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Survey of Flue Gas Desulfurization Systems Cane Run Station, Louisville Gas and Electric Company

PEDCo-Environmental, Inc.
Cincinnati, OH

Prepared for

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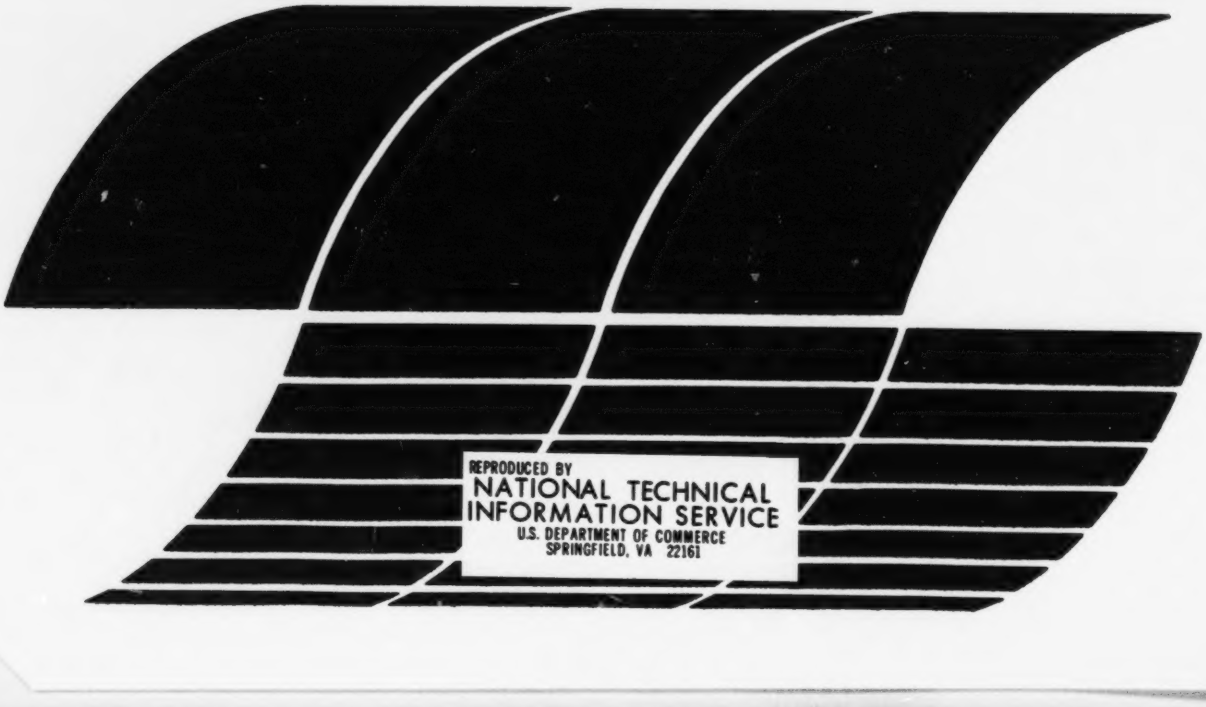

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Survey of Flue Gas Desulfurization Systems:
Cane Run Station, Louisville Gas and Electric Co.

by

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ABSTRACT

The report gives results of a survey of operational flue gas desulfurization (FGD) systems on coal-fired utility boilers in the U.S. The FGD systems installed on Units 4,5, and 6 at the Cane Run Station are described in terms of design and performance. The Cane Run No. 4 FGD system is a two-module (packed tower) carbide lime scrubber, retrofitted on a 178 MW (net) coal-fired boiler. The system, supplied by American Air Filter, commenced initial operation in August 1976. The Cane Run No. 5 FGD system is a two-module (spray tower) carbide lime scrubber, retrofitted on a 183 MW (net) coal-fired boiler. The system, supplied by Combustion Engineering, commenced initial operation in December 1977. The Cane Run Unit 6 FGD system is a two-module (tray tower) dual alkali (sodium carbonate/lime) scrubber, retrofitted on a 278 MW (net) coal-fired boiler. The system, supplied by A.D. Little/ Combustion Equipment Associates, commenced initial operation in December 1978.

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SUMMARY

The Cane Run Power Station is an existing coal-fired facility owned and operated by the Louisville Gas and Electric Company (LG&E). It is situated along the Ohio River in an industrialized area of Louisville, Kentucky. The station's combined net generating capacity of 1007 MW is provided by six coal-fired power-generating units. Each unit is equipped with its own steam generator, turbine generator, emission controls, and stack.

A high sulfur, bituminous-grade, Kentucky coal is burned at the station. This coal has an average heating value of 25,600 J/g (11,000 Btu/lb) and average ash, sulfur, and chloride contents of 14.1, 4.1, and 0.07 percent, respectively.

All of the Cane Run units are equipped with electrostatic precipitators (ESP's) for the control of fly ash. In addition, Cane Run 4, 5, and 6 are equipped with flue gas desulfurization (FGD) systems for the control of sulfur dioxide. The decision to equip these boilers with FGD systems was made after a number of discussions were held with the U.S. Environmental Protection Agency, the Air Pollution Control District of Jefferson County, and the Kentucky State Division of Air Pollution in 1974 and 1975. The intent of these discussions was to establish a compliance plan for sulfur dioxide control at all of LG&E's facilities in Jefferson County. The final result of these discussions was the signing of a consent decree on December 10, 1975, which mandated the installation of sulfur dioxide removal equipment on various boilers at LG&E's Cane Run and Mill Creek stations. This enforcement order specifically required sulfur dioxide removal systems for Cane Run 4, 5, and 6 and Mill Creek 1 and 2.

As a result of the consent decree, LG&E awarded a contract to American Air Filter on April 19, 1974, to supply an FGD system which would be retrofitted on Cane Run 4. This FGD system, which consists of two parallel wet scrubbing modules utilizing carbide lime slurry as the absorbent, is designed to remove 85 percent of the sulfur dioxide in the flue gas. Construction of the system commenced on October 15, 1974, and initial system startup occurred on August 3, 1976. The system was declared commercial approximately one year later when it successfully completed compliance and guarantee testing.

During the interim period between initial startup and commercial startup, a number of major operating problems were encountered which required numerous modifications and ultimately necessitated a basic redesign of the FGD system. The major problems encountered during this phase of operation included excessive system pressure drop, poor gas flow distribution, malfunction of the spray nozzles and spray pumps, mist eliminator inefficiency, failure of the lining materials on the outlet ductwork and stack, and inadequate slurry recirculation rates to the absorption zone of the scrubber modules. As a result, the FGD system produced sulfur dioxide removal efficiencies of 70 to 80 percent (well below the 85 percent design guarantee for 4 percent sulfur coal) and the operation of the boiler was limited to a maximum capacity of 150 to 155 MW (well below the maximum net generating capacity of 178 MW).

During the course of a scheduled unit shutdown, which extended from mid-April to mid-July 1977, all repairs and modifications were performed. This included relining of the stack and outlet ductwork; replacing the mist eliminators and pH meters; installing reheaters, turning vanes, and additional spray headers; and increasing the recirculation pump capacity.

These modifications were completed in July 1977. Early in August, the system was tested for compliance with Jefferson County and Federal sulfur dioxide air emission regulations. The modifications enabled the system to meet the Jefferson County removal requirement of 85 percent and the Federal standard of 516 ng/J (1.2 lb/10^6 Btu). The testing was handled by EPA personnel and a sulfur dioxide removal efficiency of 86 to 89 percent was attained for coal containing 3.3 to 3.4 percent sulfur. This efficiency is equivalent to an outlet emission value of 344 ng/J (0.8 lb/10^6 Btu).

With respect to system dependability, the Cane Run 4 FGD system achieved high operability* values for operation during and subsequent to initial startup. For the first 6 months following initial startup, the system performed at an operability of 92 percent. During the subsequent 6 months, however, the system remained out of service for virtually the entire period because of winter weather conditions which hampered lime deliveries to the plant, and because of the extensive system repairs and modifications required to achieve design performance. Following the successful completion of acceptance testing and initiation of commercial operation in August 1977, the FGD system has performed at an operability of approximately 90 percent for the period extending through September 1979. The only periods of system inactivity that occurred during this time resulted primarily from external conditions such as severe winter weather conditions, the coal miners' strike of 1978, boiler and turbine repairs, and scheduled annual unit overhauls.

LG&E was also mandated by the consent decree to retrofit sulfur dioxide controls on Cane Run 5. On April 21, 1975, a contract was awarded to Combustion Engineering to supply an FGD system for Cane Run 5. This FGD system is similar to the Cane Run 4 system in that the boiler is equipped with two parallel scrubbing modules designed to remove 85 percent of the sulfur dioxide from 100 percent of the boiler flue gas from the 192-MW (net) unit. Carbide lime is also used as the sulfur dioxide absorbent.

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*Operability: the number of hours the FGD system is in operation divided by the number of hours the boiler is in operation for a period, expressed as a percentage.

Construction of the Cane Run 5 FGD system commenced on October 1, 1975, and initial system startup occurred on December 29, 1977. Operation of the system during the months subsequent to initial startup was sporadic primarily because of activities related to construction completion, the coal miners' strike which eventually forced the unit out of service for approximately 2 months, and a variety of minor FGD-related problems which are normally encountered during system startup. The FGD system was returned to service on March 24, 1978. During the months that followed (mid-May to mid-July 1978), a series of performance tests were conducted in order to demonstrate contractual guarantees and compliance with air emission regulations. The results of the emission tests indicated that the FGD system was able to remove better than 90 percent of the inlet sulfur dioxide as well as provide a high degree of secondary particulate control. Following the successful completion of these tests, the system was certified commercial. Performance of the system subsequent to commercial startup has been characterized by a high degree of system dependability with an average operability index of approximately 80 percent. Periods of system activity during commercial operation have been caused by severe winter weather conditioning and FGD-related problems in the form of reheater tube failures.

The FGD process selected for Cane Run 6 was a sodium carbonate/carbide lime dual alkali system. This process was developed by Combustion Equipment Associates and A.D. Little and the system was installed on Cane Run 6 as part of an EPA-funded demonstration program. Similar to the Cane Run 4 and 5 FGD systems, this system also consists of two parallel scrubber modules designed to treat 100 percent of the boiler flue gas from the 277-MW (net) unit. However, unlike the other systems, this system uses a clear liquor of soluble sodium salts to absorb the sulfur dioxide and a slurry of carbide lime to regenerate the spent sodium scrubbing liquor and produce calcium sulfite and sulfate waste solids. In addition, the system is designed to remove as much as 95 percent of the inlet sulfur dioxide when coal with a maximum sulfur content of 5 percent is burned in the boiler.

Construction of the dual alkali system commenced in the spring of 1977 and initial system startup occurred in early April 1979. Acceptance testing has not yet been performed to certify the system ready for commercial service.

LG&E has reported the total capital and annual costs associated with the Cane Run 4 and 5 FGD systems. Total installed capital costs for these systems are \$66.6/kW and \$62.4/kW, respectively. These values are expressed in terms of the gross unit capacity and represent all direct and indirect capital expenditures made prior to startup. The annual costs for both of these systems amount to 2.5 to 3.0 mills/kWh and represent estimated operating and maintenance costs incurred during 1977 and expressed in terms of net unit capacity.

Although the Cane Run 6 FGD system has not yet been declared commercial, estimated capital and annual costs have been prepared by the demonstration project participants. The estimated capital costs amount to \$57.9/kW and include all direct and indirect costs expressed in terms of gross peak generating capacity. The estimated annual costs amount to 3.2 mills/kWh and include all variable and fixed costs expressed in terms of gross peak generating capacity.

Tables 1, 2, and 3 summarize data on the facilities and FGD systems for Cane Run 4, 5, and 6, respectively.

TABLE 1. FACILITY AND FGD SYSTEM DATA FOR CANE RUN 4

Unit rating (gross), MW	190
(net), MW	182
Fuel	Coal
Average fuel characteristics:	
Heating value, J/g (Btu/lb)	25,600 (11,000)
Ash, percent	14.1
Moisture, percent	9.6
Sulfur, percent	4.1
Chloride, percent	0.07
FGD process	Lime (carbide)
FGD system supplier	American Air Filter
Application	Retrofit
Status	Operational
Startup date:	
Initial	August 1976
Commercial	August 1977
Design removal efficiency:	
Particulate, percent	99.0[a]
Sulfur dioxide, percent	85.0
Actual removal efficiency:	
Particulate, percent	99.0
Sulfur dioxide, percent	86-89[b]
Sludge disposal	Stabilized sludge disposed in an on-site pond
Economics:	
Capital, $/kW (gross)	66.6
Annual, mills/kWh	2.75[c]

[a] Provided by upstream ESP's.

[b] Results of acceptance tests.

[c] Estimate of operating and maintenance costs for 1977.

TABLE 2. FACILITY AND FGD SYSTEM DATA FOR CANE RUN 5

Unit rating (gross), MW	200
(net), MW	192
Fuel	Coal
Average fuel characteristics:	
Heating value, J/g (Btu/lb)	25,600 (11,000)
Ash, %	14.1
Moisture, %	9.6
Sulfur, %	4.1
Chloride, %	0.07
FGD process	Lime (carbide)
FGD system supplier	Combustion Engineering
Application	Refrofit
Status	Operational
Startup date:	
Initial	December 1977
Commercial	July 1978
Design removal efficiency:	
Particulate, %	99.0[a]
Sulfur dioxide, %	85.0
Actual removal efficiency:	
Particulate, %	99.0
Sulfur dioxide, %	91[b]
Sludge disposal	Stabilized sludge disposed in on-site pond
Economics:	
Capital, $/kW (gross)	$62.4
Annual, mills/kWh (net)	2.75[c]

[a] Provided by upstream ESP's.

[b] Results of acceptance tests.

[c] Estimate of operating and maintenance costs for 1977.

TABLE 3. FACILITY AND FGD SYSTEM DATA FOR CANE RUN 6

Unit rating (gross), MW	299
(net), MW	277
Fuel	Coal
Average fuel characteristics:	
Heating value, J/g (Btu/lb)	25,600 (11,000)
Ash, %	14.1
Moisture, %	9.6
Sulfur, %	4.1
Chloride, %	0.07
FGD process	Dual alkali
FGD system supplier	Combustion Equipment Associates/ A.D. Little
Application	Retrofit
Status	Operational
Startup date:	
Initial	April 1979
Commercial	
Design removal efficiency:	
Particulate, %	99.0[a]
Sulfur dioxide, %	95.0[b]
Actual removal efficiency:	
Particulate, %	99.0
Sulfur dioxide, %	Not available
Sludge disposal	Stabilized sludge disposed in on-site pond
Economics:[c]	
Capital, $/kW (gross)	57.9
Annual, mills/kWh	3.24

[a] Provided by upstream ESP's.

[b] Maximum efficiency for coal sulfur contents of 5 percent and greater.

[c] Estimated values.

SECTION 1

INTRODUCTION

The Industrial Environmental Research Laboratory (IERL) of the U.S. Environmental Protection Agency (EPA) has initiated a study to evaluate the performance characteristics and reliability of flue gas desulfurization (FGD) systems operating on coal-fired utility boilers in the United States.

This report, one of a series on such systems, covers the Cane Run Power Station of the Louisville Gas and Electric Company (LG&E). It includes pertinent process design and operating data, a description of major startup and operating problems and solutions, atmospheric emissions data, and capital and annual cost data.

This report is based on information obtained during and after plant inspections conducted for PEDCo Environmental personnel on February 22, 1978, and September 11, 1979, by LG&E. The information presented in this report is current as of September 1979.

Section 2 provides information and data on facility design and operation; Section 3 provides background information and a detailed description of the FGD processes; Section 4 describes and analyzes the operation and performance of the FGD systems; and Section 5 provides capital and annual cost data of the FGD systems. Appendices A through F contain details of plant and system operation, economic data, and photos of the installation.

SECTION 2

FACILITY DESCRIPTION

The Cane Run Power Station is an existing coal-fired power-generating station owned and operated by LG&E. Located in Jefferson County, Kentucky, the plant is situated along the Ohio River in a moderately industrialized area of Lousiville (population: 333,000).

The station contains six coal-fired steam electric generators which are capable of producing a maximum net generating capacity of 1007 MW. Cane Run 1, 2, and 3, which are the older units at the station, are rated 106, 109, and 141 MW (net), respectively. Cane Run 4, 5, and 6, which have been in service for 19, 16, and 12 years, respectively, are rated 182, 192, and 277 MW (net), respectively. The station capacity factor for operation in 1977 was approximately 50 percent. Table 4 provides a summary of the Cane Run units, including gross and net generating capacities, heat rates, and capacity factors.

A high sulfur bituminous grade Kentucky coal is burned at the station. This coal originates primarily from the Star Mine which is owned by the Peabody Coal Company and located in the western part of the state. This coal has an average heating value of 25,600 J/g (11,000 Btu/lb) and average ash, moisture, sulfur, and chloride contents of 14.1, 9.6, 4.1, and 0.07 percent, respectively. Approximately 900 Mg (2 million tons) of this coal are burned annually at this station.

In order to meet air emission regulations of the Air Pollution Control District of Jefferson County, the Kentucky State Division of Air Pollution, and the U.S. EPA, each unit at Cane

TABLE 4. SUMMARY OF THE CANE RUN POWER-GENERATING UNITS

Unit	Capacity, MW		Heat rate, J/net kWh (Btu/net kWh)	Capacity factor, percent
	Gross	Net		
1	110	106	11,426 (10,830)	N.A.[a]
2	113	109	11,035 (10,460)	N.A.[a]
3	147	141	10,772 (10,210)	N.A.[a]
4	190	182	10,740 (10,180)	55
5	200	192	10,529 (9,980)	60
6	299	277	10,508 (9,960)	60
Total (average)	1059	1007		(50)[b]

[a] Individual unit capacity factors are not available. The combined capacity factor for Units 1, 2, and 3 was approximately 34 percent for 1977.

[b] Station capacity factor for 1977.

Run is equipped with an emission control system. Cane Run 1 through 6 are equipped with electrostatic precipitators (ESP's) for the control of fly ash. In addition, Cane Run 4, 5, and 6 are equipped with flue gas desulfurization (FGD) systems for the control of sulfur dioxide. The FGD systems provided for each unit consist of two parallel scrubber modules designed to treat 100 percent of the boiler flue gas for each unit at full load. The Cane Run 4 and 5 FGD systems use a slurry of carbide lime for removal of sulfur dioxide and the sulfur-bearing calcium waste solids produced are disposed on the plant site. The Cane Run 6 FGD system uses a clear solution of soluble sodium salts for removal of sulfur dioxide and carbide lime slurry to regenerate the spent scrubbing solution and produce sulfur-bearing calcium waste solids. The Cane 4 and 5 FGD systems are supplied by American Air Filter (AAF) and Combustion Engineering (C-E), respectively. Initial and commercial startup dates for these systems are August 3, 1976, and August 7, 1977, respectively, for Cane 4; and December 29, 1977, and July 14, 1978, respectively, for Cane Run 5. The Cane Run 6 FGD system is supplied by Combustion Equipment Associates and A.D. Little (CEA/ADL). Initial startup of this system occurred in early April 1979. Acceptance testing has not yet been completed for commercial certification of this FGD system.

For Cane Run 4, 5, and 6, maximum particulate emissions allowable under regulations of the Air Pollution Control District of Jefferson County, the Kentucky State Division of Air Pollution, and the U.S. EPA are 43 ng/J (0.1 lb/10^6 Btu) of heat input to the boiler. Maximum allowable sulfur dioxide emissions are limited by a continuous removal requirement of 85 percent and a weight limitation of 516 ng/J (1.2 lb/10^6 Btu) of heat input to the boiler. Actual sulfur dioxide emissions, as measured by EPA personnel during compliance testing for Cane Run 4, were 344 ng/J (0.8 lb/10^6 Btu), which was equivalent to an 86 to 89 percent sulfur dioxide removal efficiency for coal containing 3.3 to 3.4

percent sulfur. For Cane Run 5, sulfur dioxide emissions measured during performance testing were 211 to 249 ng/J (0.49 to 0.58 lb/10^6 Btu), which was equivalent to a 91 percent sulfur dioxide removal efficiency.

Table 5 summarizes data on plant design and operation.

TABLE 5. DESIGN, OPERATION, AND EMISSION DATA:
CANE RUN 4, 5, AND 6

Description	Cane Run 4	Cane Run 5	Cane Run 6
Generating capacity, MW			
Gross	190	200	299
Net without FGD	185	195	280
Net with FGD	182	192	277
Maximum coal consumption, Mg/h (tons/h)	76 (84)	79 (87)	113 (125)
Maximum heat input GJ/h (10^6 Btu/h)	1,955 (1,852)	2,022 (1,916)	2,911 (2,756)
Maximum flue gas rate m^3/s (10^3 acfm)	346 (734)	307 (650)	503 (1,065)
Flue gas temperature, °C (°F)	163 (325)	163 (325)	149 (300)
Unit heat rate, kJ/net kWh (Btu/net kWh)	10,740 (10,180)	10,529 (9,980)	10,508 (9,960)
Unit capacity factor, percent (1977)	55	60	60
Emission controls:			
Particulate	ESP	ESP	ESP
Sulfur dioxide	Packed tower absorbers	Spray tower absorbers	Tray tower absorbers
Particulate emission rate:			
Allowable, ng/J (lb/10^6 Btu)	43 (0.1)	43 (0.1)	43 (0.1)
Actual, ng/J (lb/10^6 Btu)	43 (0.1)	15 - 26 (0.04 - 0.06)	43 (0.1)
Sulfur dioxide emission rate:			
Allowable, ng/J (lb/10^6 Btu)	516 (1.2)	516 (1.2)	516 (1.2)
Actual, ng/J (lb/10^6 Btu)	344 (0.8)	211 - 249 (0.49 - 0.58)	N.A.[a]

[a] Not available; acceptance testing has not yet been performed.

SECTION 3

FLUE GAS DESULFURIZATION SYSTEM

BACKGROUND INFORMATION

Process Development

In 1970, LG&E was faced with the dilemma of imminent stringent ambient air standards for sulfur dioxide emissions from their coal-fired plants and a contractural commitment to a long-term supply of high sulfur coal. As such, LG&E requested Combustion Engineering (C-E) to evaluate their marble-bed scrubber design for application in a lime slurry FGD system on a coal-fired boiler at their Paddy's Run Power Station. This evaluation was based on the development of a process design that was compatible with carbide lime as the absorbent. Carbide lime is a by-product of the manufacture of acetylene and is mainly composed of calcium hydroxide and calcium carbonate. The request to develop a process that could use carbide lime stemmed from LG&E's easy access to supplies of this by-product from a local acetylene manufacturing plant operated by Airco.

In early 1971, a laboratory pilot plant program was conducted at C-E's Kreisinger Laboratory. A 34-m^3/min (1200-acfm) pilot plant scrubber was used to establish the feasibility of removing 80 percent of the inlet sulfur dioxide from a flue gas stream containing 2000 ppm sulfur dioxide. Using carbide lime lime as the absorbent, an optimum scrubber design was developed which was capable of achieving design removal efficiency without scaling while operating in an open water loop.

In June 1971, a prototype plant program was conducted at Kreisinger to verify the results of the laboratory pilot plant program. A 340-m^3/min (12,000-acfm) prototype plant scrubber was operated through a 100-h test program to verify and refine system design parameters. The prototype plant test program essentially verified the results obtained from the laboratory pilot plant test program.

In early 1972, another prototype plant test program was again conducted at Kreisinger [340 m^3/min (12,000 acfm)] to demonstrate the feasibility of achieving these results while operating in a closed water loop. For two months the prototype plant demonstrated closed water loop operation with no decline in overall performance. The results of the various pilot and prototype plant test programs conducted at Kreisinger are summarized in Table 6.

As a result of these successful test programs, LG&E authorized C-E to proceed with the design and installation of a demonstration-scale FGD system on Paddy's Run 6, a 65-MW (net) coal-fired unit. This unit was selected for the demonstration because of space available for retrofit. The intent of this demonstration was to determine the design and performance capabilities of a carbide lime slurry FGD system on a full-size, high sulfur, coal-fired unit. Based on the outcome of this demonstration program, LG&E was required to develop a sulfur dioxide control program for its coal-fired generating stations in order to comply with ambient air standards.

On-site construction of the Paddy's Run FGD system commenced in June 1972 and was completed in April 1973. Initial startup occurred on April 5, 1973, and system shakedown was completed by the following July.

Process Design

The Paddy's Run FGD system consists of two identical scrubber modules arranged in parallel. Each scrubber module is designed to treat 50 percent of the boiler flue gas at full load, which is equivalent to 82.6 m^3/s (175,000 acfm) of flue gas at

TABLE 6. SUMMARY OF KREISINGER TEST PROGRAMS: 1971 to 1972

Test unit	Pilot	Prototype	Prototype	Prototype
Test duration, h (mo)		75	20	(2)
Capacity, m^3/s (acfm)	34 (1200)	340 (12,000)	340 (12,000)	340 (12,000)
Design	Double marble bed	Double marble bed	Double marble bed	Double marble bed
Absorbent	Carbide lime	Carbide lime	Carbide lime	Carbide lime
Stoichiometric ratio[a]	1.0	1.0	1.0	1.0
Slurry pH[b]	9 - 10	10	10	<10
Liquid/gas ratio, liters/m^3 (gal/1000 acf)[c]	2.6 (20)	2.6 (20)	3.3 (25)	2.6 (20)
Slurry recycle, percent[d]	45	45	90	90
Water loop	Open	Open	Open	Closed
Liquid blowdown, liters/m^3 (gal/1000 acf)		0.6 (5)	0.6 (5)	None
Sulfur dioxide concentration, ppm	2000	2000	2000	2000
Sulfur dioxide removal efficiency:				
Design, percent	80	80	80	80
Actual, percent	75-80	80	90	87

[a] Moles of absorbent (CaO) per mole of sulfur dioxide removed.

[b] Control level of slurry feed to underbed streams.

[c] Per bed.

[d] The protion of scrubber effluent slurry recycled to the scrubber through the reaction tank.

177°C (350°F). Each scrubber module is equipped with two marble beds which facilitate intimate mixing of the gas and scrubbing slurry. Each marble bed contains a 7.6-cm (3-in.) layer of 2.5-cm (1.0-in.) diameter glass spheres. Each scrubber is also equipped with a two-stage mist eliminator which removes entrained droplets carried over in the gas from the scrubbing zone. The discharge duct of each scrubber module is equipped with two natural gas burners designed to raise the temperature of the saturated gas stream 22°C (40°F) prior to passage through a booster fan [1100 kW (1500 hp)] to the existing stack.

Carbide lime scrubbing slurry is sprayed cocurrently with the gas stream to the underside of each marble bed at a rate of 256 liters/s (4050 gpm). This is equivalent to a liquid to gas ratio (L/G) of approximately 2.1 liters/m^3 (1[illegible] gal/1000 acf) per bed. The carbide lime slurry is delivered to each scrubber module by a battery of 3 spray pumps, 2 of which are required for operation at full load. Spent scrubbing slurry is collected by overflow pots located on the top side of each marble bed and returned via gravity feed to a series of external reaction tanks. Each scrubber module is also equipped with a divided internal hold tank which collects slurry not carried away by the overflow pots. A sloping screen segregates the internal hold tank into two parts, a bottom half and top half, each of which is equipped with an agitator. The screen collects large particles and purges them along with spent scrubbing slurry collected in the top half via an effluent bleed pump (one per scrubber module) to a thickener. The slurry collected in the bottom half of the divided hold tank is transferred by a drain pump (one operational and one common spare per scrubber module) to the external reaction tanks.

The spent slurry is collected in the primary reaction tank which is an agitated, 750,000-liter (210,000 gal) capacity reactor. Fresh carbide lime slurry is fed to the primary reactor as well as thickener overflow, fresh makeup water, and vacuum filtrate. The carbide lime is added to this tank along with the scrubber internal hold tank bottoms in a small cylindrical mixing well in order to insure intimate mixing and completion of chemical reactions. This tank provides a 20-minute retention time. A secondary reaction tank (surge tank) downstream from the primary reactor provides additional slurry holdup in order to ensure completion of chemical reactions. Slurry is then pumped back to the marble beds in the scrubber modules by the slurry spray pumps.

A 10 percent solids stream is bled from the slurry recirculation loop to the thickener in order to remove the reaction products which accumulate in the scrubbing slurry. The thickener has a diameter of 15.2 m (50 ft) and a liquid capacity of 777,900 liters (205,500 gal). The waste slurry is concentrated to a 25 percent solids sludge in the thickener and the underflow is sent to a rotary drum vacuum filter for further concentrating. Two rotary drum vacuum filters are provided for final dewatering, one of which is a spare. Each filter has an effective filtering area of 14 m^2 (150 ft^2) and is designed to produce 9 Mg/h (10 tons/hr) of 45 percent solids filter cake. During the dewatering process, lime and dry fly ash are added to the waste slurry in order to stabilize the sludge product for disposal in an off-site landfill.

A simplified process flow diagram of the Paddy's Run FGD system is provided in Figure 1. Design conditions and operating parameters for the Paddy's Run FGD system are provided in Tables 7, 8, 9, 10, 11, 12, and 13.

System Performance

On April 6, 1973, initial operation of the FGD system was achieved with one scrubber module placed in the flue gas path. From April 6 to early October 1973, the FGD system operated approximately 1000 h on an intermittent basis. During this period, the system was checked out and modifications were made to the thickener, lime feed system, mist eliminator wash system, and system controls. On October 26, 1973, an extended 30-day test

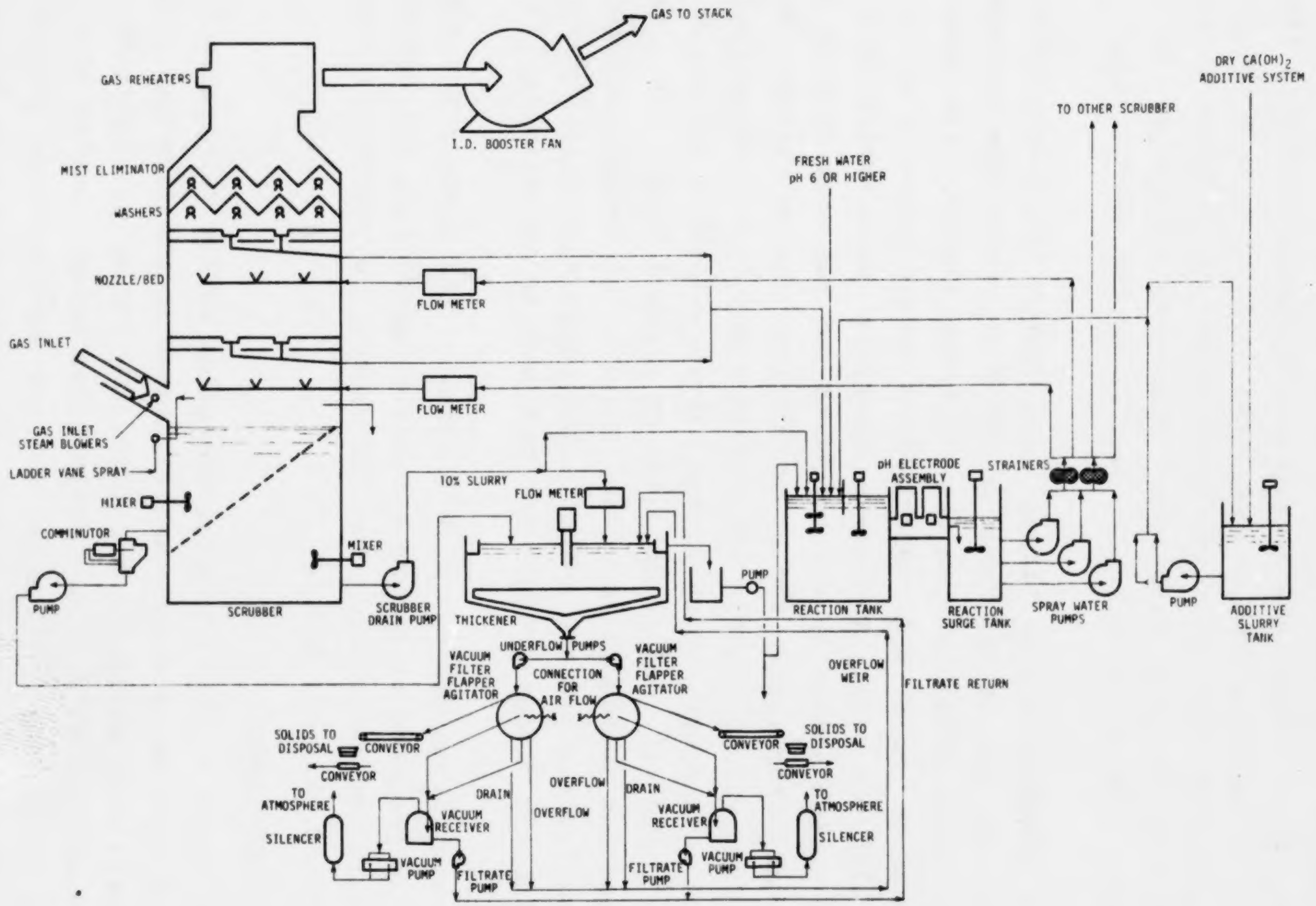
GAS TO STACK
GAS REHEATERS
I.D. BOOSTER FAN
DRY CA(OH)2 ADDITIVE SYSTEM
TO OTHER SCRUBBER
FRESH WATER pH 6 OR HIGHER
MIST ELIMINATOR
WASHERS
NOZZLE/BED
FLOW METER
GAS INLET
FLOW METER
GAS INLET STEAM BLOWERS
LADDER VANE SPRAY
MIXER
COMMINUTOR
PUMP
SCRUBBER
MIXER
SCRUBBER DRAIN PUMP
10% SLURRY
FLOW METER
THICKENER
PUMP
pH ELECTRODE ASSEMBLY
STRAINERS
REACTION TANK
REACTION SURGE TANK
SPRAY WATER PUMPS
PUMP
ADDITIVE SLURRY TANK
UNDERFLOW PUMPS
VACUUM FILTER FLAPPER AGITATOR
CONNECTION FOR AIR FLOW
VACUUM FILTER FLAPPER AGITATOR
OVERFLOW WEIR
FILTRATE RETURN
SOLIDS TO DISPOSAL
CONVEYOR
CONVEYOR
CONVEYOR
SOLIDS TO DISPOSAL
CONVEYOR
TO ATMOSPHERE
SILENCER
VACUUM PUMP
VACUUM RECEIVER
FILTRATE PUMP
DRAIN
OVERFLOW
OVERFLOW
DRAIN
VACUUM RECEIVER
FILTRATE PUMP
VACUUM PUMP
TO ATMOSPHERE
SILENCER

Figure 1. Simplified process flow diagram of Paddy's Run 6 FGD system.

TABLE 7. SUMMARY OF DATA: SCRUBBER MODULES

Number of modules	2
Type	Marble bed
Dimensions, m (ft)	5.2 (17), 5.5 (18), 15.2 (50)
Capacity, m^3/s (acfm)	82.6 (175,000)
Superficial gas velocity, m/s (ft/s)	3.0 (10)
Liquid/gas ratio, liters/m^3 (gal/1000 acf)	2.1 (16)
Equipment internals:	
Number of beds	2
Bed packing thickness, cm (in)	7.6 (3)
Marble sphere diameter	2.5 (1)
Materials of construction:	
Shell	Carbon steel
Lining	Flake glass polyester
Plates	316L stainless steel
Supports	316L stainless steel
Drain pots	316L stainless steel

TABLE 8. SUMMARY OF DATA: MIST ELIMINATORS

Number	2
Number per module	1
Type	Chevron
Configuration (relative to gas flow)	Horizontal
Shape	Z-shape, 120-degree bends
Number of stages	2
Number of passes	3
Distance between stages, m (ft)	1.2 (4)
Distance between vanes, cm (in.)	3.8-5.1 (1.5-2.0)
Freeboard distance, m (ft)	1.5 (5)
Pressure drop, kPa (in. H_2O)	0.25 (1.0)
Materials of construction	FRP
Wash system:	
Water source	River water
Wash duration, min/h	10-15/8
Wash rate, liters/s (gpm)	5.0-12.6 (80-200)
Wash pressure, kPa (psig)	377-550 (40-65)

TABLE 9. SUMMARY OF DATA: REHEATERS

Number	4
Number per module	2
Type	Direct combustion
Fuel	Natural gas
Fuel rate, m^3/min (scfh)	9.4 (20,000)
Heat input, GJ/h (10^6 Btu/h)	17 - 19 (16 - 18)
Excess combustion air	6 - 9
ΔT, °C (°F)	22 (40)

TABLE 10. SUMMARY OF DATA: TANKS

Category	Primary reaction tank	Secondary reaction tank (surge)	Scrubber internal hold tank	Carbide lime slurry tank
Number	1	1	2	1
Dimensions, m (ft)	14.6 x 5.2 (48 x 17)	6.1 x 4.6 (20 x 15)	4.6 x 5.2 x 4.9 (15 x 17 x 16)	2.4 x 5.2 (8 x 17)
Capacity, liter (gal)	795,000 (210,000)	133,250 (35,200)	61,700 (16,300)	24.230 (6,400)
Retention time, min	20	3	3	150
Temperature	52 (125)	52 (125)	52 (126)	Ambient
pH	8	8	4.6-5.3	12.6
Solids	10	10	10	10
Specific gravity	1.1	1.1	1.1	1.1
Agitators:				
Number	2	1	2	1
Rating, kW (hp)	10 (15) & 40 (50)	10 (15)	8 (10)	4 (5)
Materials of construction:				
Shell	Carbon steel	Carbon steel	Carbon steel	Carbon steel
Lining			Flake glass polyester	

TABLE 11. SUMMARY OF DATA: THICKENER

Number	1
Dimensions, m (ft)	15.2 x 4.3 (50 x 14)
Capacity, liters (gal)	777,900 (205,500)
Solids concentration:	
Inlet, percent	10
Outlet, percent	25
Retention time, hr[a]	4.3
Materials of construction	Carbon steel

[a] At full load.

TABLE 12. SUMMARY OF DATA: VACUUM FILTERS

Number	2
Operating schedule	1 operational/1 spare
Cloth area/filter, m^2 (ft^2)	14 (150)
Feed stream characteristics:	
Liters/s (gpm)	5 (80)
Solids, percent	25
Product characteristics:	
Solids, percent	45
Wet filter cake, Mg/h (ton/h)	9 (10)
Dry solids, Mg/h (ton/h)	3.7 (4.1)

TABLE 13. SUMMARY OF DATA: MAJOR PUMPS

Number	Service	Manu-facturer	Model	Performance						Operation
				Materials of construction	Motor kW (hp)	Capacity, liters/s (gpm)	Speed, rpm	Solids, percent	Head m (ft)	
6	Slurry recirculation	Allis chalmers		Ni-Hard	335 (450)	380 (6000)	1000	10	36 (140)	4 operational, 2 spare
2	Slurry feed	Worthington	ER-3729-2-1/2R091	Cast iron (casing and impeller)	3.7 (5)	6.3 (100)	1800	25	18 (60)	2 operational
2	Thickener overflow	Allis chalmers	912	Rubber-lined (casing and impeller)	22 (30)	19 (300)	1800	<1	36 (120)	1 operational, 1 spare
2	Thickener underflow	Allen Shermanhoff	AA-6-5	Rubber-lined (casing and impeller)	3.7 (5)	9.5 (150)	1800	25	36 (120)	1 operational, 1 spare

run was initiated to demonstrate system reliability. The operating criteria for the test required one scrubber module remain in service while the other module would float with system load demand. This test was completed on November 30, 1973, after 854 h of continuous operation. During the test, measurements indicated that the FGD system's sulfur dioxide removal efficiency exceeded design (85 percent) and the outlet particulate loadings were 68.6 to 91.5 mg/m^3 (0.030 to 0.040 gr/dscf).

By the end of 1973, module A had logged 1318 hours of operation and module B had logged 2425 hours of operation. This translates into annual operability* factors of 39 and 71 percent for modules A and B, respectively.

The FGD system was returned to service in July 1974 to meet LG&E's summer peak generating demand. During this period of operation, the unit and FGD system were operated on an 8-to-5, Monday-through-Friday schedule. Module A logged 417 h of operation and Module B 517 h, which are equivalent to operability factors of 67 and 83 percent, respectively. The operation of the FGD system during this period was significant because of variations in the carbide lime additive. The magnesium oxide content ranged to a maximum of 2.2 percent (up from previous levels of 0.1 percent) and the concentration of a soluble oxidation inhibitor dropped off to low or nonexistent levels. As such, the following effects on system performance were noted:

(1) Sulfur dioxide removal increased on the average 3 or 4 percent to the 90 percent level.

(2) Sulfur dioxide emission levels decreased from approximately 140 ppm to 60 ppm.

(3) Magnesium ion concentrations in the scrubbing slurry increased from approximately 100 to 1500 ppm.

(4) Dissolved solids levels in the scrubbing slurry increased to 7000 to 8000 ppm.

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*Operability: the number of hours the FGD system (or individual modules) is in operation divided by the number of hours the boilers in operation for a period, expressed as a percentage.

(5) Oxidation increased to the 10 percent level on a molar basis.

The FGD system was again returned to service late in the summer of 1975 when the unit was pressed into service to meet summer peak demand. During the remainder of the year, the unit and FGD system were operated intermittently, on an 8-to-5, Monday-through-Friday schedule. During this period of operation, no major problems were encountered and system operability was approximately 98 percent for both modules. High sulfur dioxide removal efficiencies, on the order of 98 percent, were recorded during this period of operation.

The FGD system continued to operate intermittently in 1976 through peak demand periods. During the course of the year, preparations were made to conduct an EPA-subsidized scrubber and sludge evaluation study. This study, which commenced on October 25, 1976, consisted of four phases: carbide lime characterization and sludge mixing, commercial lime testing and sludge mixing, hold tank modifications, and magnesium and chloride ion addition testing. Testing was conducted on one of the system's two modules.

The first phase of operation was completed in December 1976. Basically, this phase of testing was devoted to characterizing the FGD system as it normally operated. The second phase of operation, commercial lime testing, commenced in mid-March 1977. With commercial lime as the scrubbing reagent, the system operated at elevated gypsum saturation levels (1.1 to 1.6) and oxidation levels (13 to 15 percent), and varying amounts of gypsum scale were formed in the system. Carbide lime slurry was reintroduced into the system in order to clean up the scale condition in the scrubber. A form of carbide lime ("black lime") was used that contained high concentrations of magnesium (as high as 2.2 percent), providing slurry concentrations in the range of 1000 to 1600 ppm. After a few days of operation with carbide lime, the scale formed in the system dissolved and subsaturated conditions were reestablished.

From June 18 to August 31, 1977, the last phases of the test program were completed. The most interesting results obtained during this period involved the magnesium and chloride addition testing. With respect to magnesium addition, the system was operated with a commercial grade lime promoted with a 55 percent slurry of magnesium hydroxide which yielded an effective magnesium ion concentration of 4000 ppm. During the course of the test, the magnesium ion concentration was gradually lowered to 2000 ppm. Sulfur dioxide removals of 99.7 to 99.9 percent were achieved with inlet sulfur dioxide loadings of 2150 to 2230 ppm and outlet loadings of 1 to 5 ppm. These removal efficiencies were accompanied by calcium sulfate relative saturations approaching zero. Maintaining the effective magnesium ion concentration in the 2400 to 3000 ppm range provided the best control for maintaining high sulfur dioxide removals and low calcium sulfate relative saturation levels.

With respect the chloride addition, calcium chloride was added to the scrubbing slurry in order to produce chloride levels of 3000 ppm, a concentration normally associated with a high chloride coal. Magnesium ion concentrations were increased to 3500 ppm in order to compensate for the increased chloride ion concentration levels. Results indicated that high sulfur dioxide removals (99 percent) and low gypsum relative saturation levels were achieved with no operational problems.

With respect to the sludge mix program, various samples of carbide lime and commercial lime sludges were mixed with fixatives in order to obtain data on permeability, unconfined compressive strengths, and leachates. Conditions evaluated during the course of the program included disposal method (lined pond, unlined pit), sludge solids (24 to 65 percent), fixatives (carbide lime, portland cement), and fixative-to-solid ratios (0:1 to 1.5:1). Preliminary results indicated that the carbide lime and commercial lime sludges achieved similar levels with respect to permeability, unconfined compressive strength, and leachates.

Following the completion of the scrubber and sludge test program, the unit and FGD system remained inactive during the balance of 1977 and operated only briefly in 1978. FGD operations in 1978 were confined to peak load periods (April and June) and one test program which involved the evaluation of a new flocculant for use at other LG&E FGD systems. The FGD system did not operate during the first 9 months of 1979 because of insufficient demand to operate the unit.

Process Selection for Future Installations

During the course of the Paddy's Run FGD demonstration program, discussions were being held with the U.S. EPA, Air Pollution Control District of Jefferson County, and the Kentucky State Division of Air Pollution regarding the reduction of sulfur dioxide emissions at LG&E's coal-fired installations. The success of the Paddy's Run FGD demonstration program, coupled with LG&E's long-term commitment to high sulfur coal for their entire system, resulted in the signing of a consent decree on December 10, 1975, with the following conditions:

(1) All the Paddy's Run units will be phased out of service by 1985 with Paddy's Run 1, 2, and 3 retired by the end of 1979 and the remaining units by 1985.

(2) Cane Run 1, 2, and 3 will be phased out of service by 1985. Cane Run 4, 5, and 6 will be equipped with FGD systems.

(3) Mill Creek 1 and 2 will be equipped with FGD systems. Mill Creek 3 and 4 are new units which will require FGD systems to achieve compliance with sulfur dioxide new source performance standards (NSPS).

(4) LG&E will have the capability to use the units phased out of service on an emergency basis which is defined as power requirements during shutdown of the FGD-equipped units.

Based on the requirements of the consent decree, LG&E awarded a contract to AAF for a carbide lime slurry FGD system for Cane Run 4. Initial startup of this system occurred on August 3, 1976. Subsequent contracts for commercial FGD systems were awarded to C-E for Cane Run 5 (carbide lime slurry) and to CEA/ADL for Cane Run 6 (dual alkali). These systems became operational on December 29, 1977, and early April 1979, respectively. Because the majority of LG&E's FGD commercial operating experience has been with Cane Run 4 and 5, the remainder of this report will be devoted to the design and performance aspects of these particular units. The Cane Run 6 FGD system will be briefly summarized with respect to design and performance characteristics.

PROCESS DESCRIPTION

Cane Run 4

The carbide lime slurry FGD system operating at Cane Run 4 was supplied by AAF in accordance with specifications prepared by LG&E's engineer, Fluor-Pioneer. The FGD system installed on Cane Run 4 is a pressurized, tail-end, wet scrubbing system which consists of two parallel scrubber modules designed to treat 346 m^3/s (734,000 acfm) of flue gas at 163°C (325°F) when the unit is operating at full load. The FGD system includes gas handling and treating equipment, slurry handling equipment, solids concentrating equipment, waste disposal and pond water return equipment, and lime preparation and handling equipment. A description of these various elements of system operation is provided in the following paragraphs. A simplified diagram of the Cane Run 4 FGD system is provided in Figure 2.

Gas Handling and Treating Equipment--

The flue gas exits the boiler and passes through existing ESP's at 346 m^3/s (734,000 acfm) and 163°C (325°F). Flue gas from existing induced-draft fans discharge through induced-draft booster fans into the FGD system. The ductwork and damper network provided with the FGD system allows gas to partially or

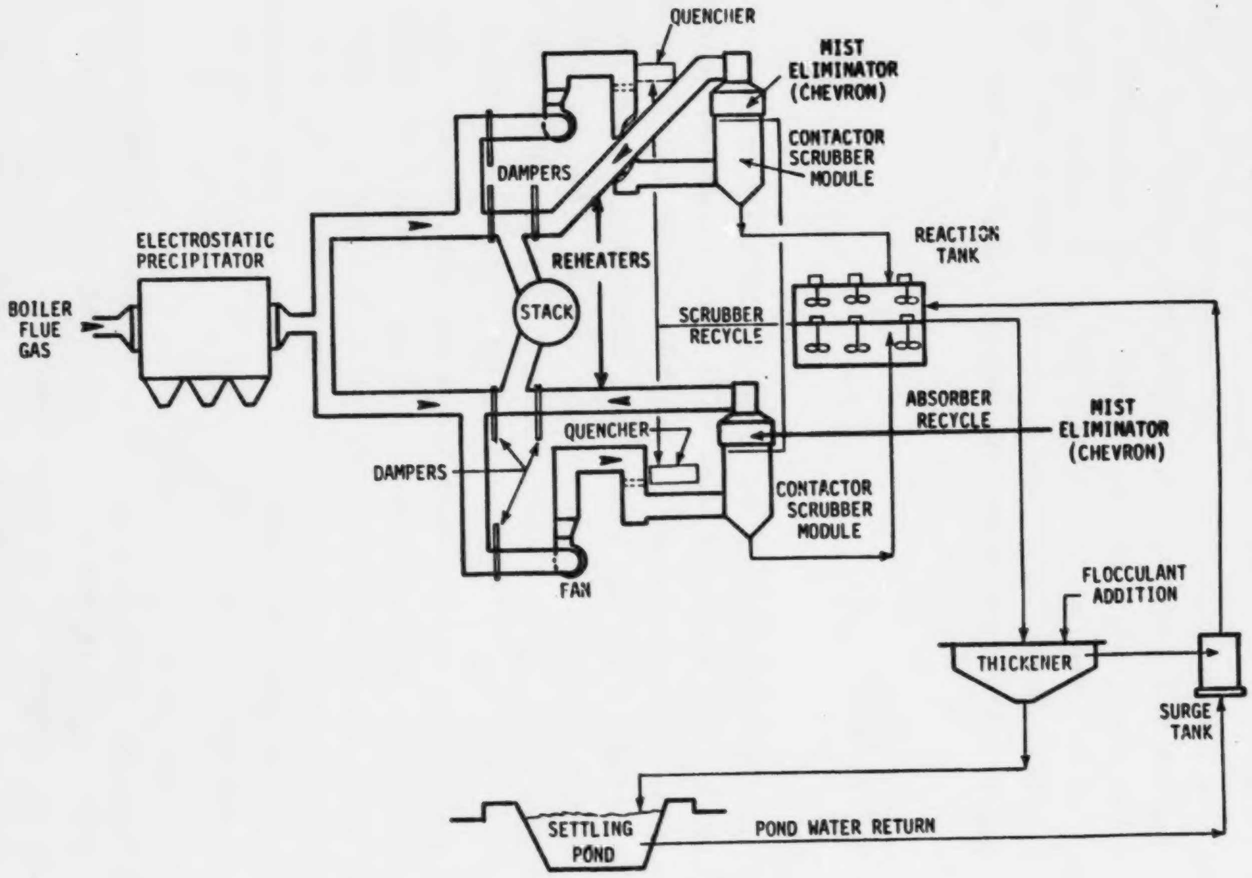
QUENCHER
MIST ELIMINATOR (CHEVRON)
CONTACTOR SCRUBBER MODULE
DAMPERS
ELECTROSTATIC PRECIPITATOR
REACTION TANK
REHEATERS
BOILER FLUE GAS
STACK
SCRUBBER RECYCLE
ABSORBER RECYCLE
MIST ELIMINATOR (CHEVRON)
QUENCHER
DAMPERS
CONTACTOR SCRUBBER MODULE
FAN
FLOCCULANT ADDITION
THICKENER
SURGE TANK
SETTLING POND
POND WATER RETURN

Figure 2. Simplified process flow diagram of Cane Run 4 FGD system.

totally bypass the scrubber modules. Guillotine isolation dampers installed at the inlet of each booster fan, at the outlet of each scrubber module, and in the bypass breeching enables gas to bypass one or both scrubber modules during boiler operation.

Following passage through the booster fans, the gas enters the scrubber modules. Eac scrubber module consists of a verticle absorber tower preceded by a quencher and flooded elbow. Each quencher is a wetted-wall conical frustrum section in the duct. A series of nozzles in the quencher inject lime scrubbing slurry into the gas stream to insure thorough wetting of the gases prior to passage through the absorber. Immediately below each quencher is a flooded elbow. This section serves as a catch basin for the spent quencher slurry and complete the saturation of the gas stream. Some removal of sulfur dioxide occurs in the quencher and flooded elbow since part of the lime slurry recycle stream is diverted to these sections for wetting and saturation.

The quenched flue gas enters the base of each absorber tower at 138 m^3/s (291,500 acfm) and 53°C (127°F). Each absorber tower is a single stage mobile bed contactor. The mobile bed contactor contains a fluid bed packing of solid spheres which serve to break up the gas stream and provide pockets for intimate mixing of the flue gases and scrubbing slurry. The flue gas passes upward through the packing where it contacts the scrubbing slurry sprayed into the gas stream countercurrently through large, low pressure, slurry sprays.

Entrained droplets of moisture and slurry picked up by the gas stream due to the turbulent mixing of slurry and gas in absorption zone are removed by mist eliminators. Each absorber is equipped with a two-stage, two-pass, chevron-type mist eliminator located in the top portion of each tower. Each mist eliminator is equipped with its own set of water sprays to retard the accumulation of solids which buildup on the chevron blades.

Following passage through the mist eliminators, the cool, saturated gas stream is reheated by oil-fired burners located in the discharge ducts entering the stack. The direct oil-fired reheaters boost the temperature of the gas stream approximately 22° to 28°C (40° to 50°F) prior to discharge to the existing stack.

Slurry Handling System--

Each scrubber module is equipped with its own compartmentalized reaction tank, recirculation pumps, and recirculation line for contacting the flue gas with scrubbing slurry. Three recirculation pumps deliver 1112 liters/s (17,625 gpm) of 10 percent solids scrubbing slurry to each scrubber module. Of this amount, 112 liters/s (1,760 gpm) is provided to the quencher and 1000 liters/s (15,865 gpm) is provided to the absorber. This slurry, as well as 5 liters/s (80 gpm) of mist eliminator wash water, drains to a cone-shaped reservior located at the base of each absorber. The spent slurry and wash water then drains through a main pipe line to the return section of the reaction tank.

The reaction tank is the heart of the slurry recirculation system. Each reaction tank is a rectangular, reinforced concrete tank which contains two partitions dividing the tank into three compartments. Each compartment represents a separate reaction area and is equipped with its own agitator, pH monitors, and level controls. Slurry flows from one compartment to the next through an opening in the bottom of the partitioning wall. During emergencies, this flow may occur over weirs placed at the top of each compartment wall.

The three compartments comprised by the reaction tank are the return section, middle section, and feed section. The return section collects the spent scrubbing slurry discharged from the cone-shaped reservoir located in the base of the absorber. Fresh carbide lime slurry is added to this section as well as thickener overflow. The fresh carbide lime slurry reacts with the spent scrubbing slurry, neutralizing the reaction products and precipitating the waste solids which are ultimately removed from the recirculation loop. Water from the thickener overflow return tank maintains proper liquid levels in the reaction tank.

The middle section of the reaction tank allows the control of recycle slurry pH and the continuation of the chemical reactions started in the return section.

The feed section of the reaction tank allows the completion of chemical reactions and triming of the pH of the recycle slurry. Solids which have precipitated in the reaction tank are removed from the bottom of the feed section by effluent bleed pumps. The recycle slurry is then returned to the quencher and absorber by the recirculation pumps.

Solids Concentrating--

The effluent bleed pumps discharge the waste solids accumulated in the slurry loop to the thickener. Approximately 14 liters/s (220 gpm) of slurry is discharged from the feed section of each reaction tank. The thickener concentrates the waste solids from approximately 10 to 25 percent. In order to aid the thickening process, a polyelectrolyte feeding system is provided to enhance precipitation within the thickener. This feeding system prepares, mixes, and ages a 0.5 percent flocculant solution which is transferred directly to the thickener on a continuous basis. The 5 to 7 ppm concentration of flocculant which results in the thickener enhances the settling characteristics of waste solids produced by the scrubbing system.

Sludge is removed from the bottom of the thickener to an onsite pond for final disposal. Clarified overflow from the thickener gravity flows to the thickener overflow return tank for return to the reaction tank return sections. Supernatant from the sludge pond is added to the thickener overflow return tank to maintain system liquid levels. In addition, the thickener overflow return tank is also equipped with an emergency overflow which can empty water directly to the pond during emergency liquid surges.

Lime Preparation and Handling Equipment--

Carbide lime is delivered to the plant as a 30 percent solids slurry. This absorbent is added to a crusher-disintegrator at a rate of 12.6 liters/s (200 gpm) at full load. The crusher-disintegrator supplies lime of the proper consistency to the reactant supply tank. Any tramp solids or other foreign matter in the carbide lime slurry are removed by the crusher-disintegrator. The reactant supply tank is an agitated hold tank from which slurry is transferred to the return section of each reaction tank. The flow of slurry from the crusher-disintegrator to the reactant supply tank is controlled by liquid levels in the tank. The flow of slurry from the reactant supply tank to the reaction tank is controlled recycle slurry pH levels.

Cane Run 5

The carbide lime slurry FGD system operating at Cane Run 5 was supplied by C-E in accordance with specifications prepared by Fluor-Pioneer. This system is similar to Cane Run 4 in process design and gas treating capacity. As such, this system is described in the same manner as that used above for Cane Run 4. A simplified process flow diagram of the Cane Run 5 FGD system is provided in Figure 3.

Gas Handling--

Flue gas exits the boiler and passes through existing ESP's to the FGD system. The FGD system consists of two 50 percent capacity scrubber modules designed to treat 307 m^3/s (650,000 acfm) of flue gas at 163°C (325°F). Each scrubber module contains a horizontal approach duct which enters the base of a vertical spray tower absorber. The flue gas enters the base of each scrubber at a velocity of 7.6 m/s (25 ft/s). As the gas enters the base of the spray tower it is decelerated to a velocity of 2.1 m/s (7 ft/s) and turned 90 degrees with the aid of ladder-type turning vanes. In this zone of the tower the gas is rapidly quenched to a temperature of 52°C (126°F). The gas then

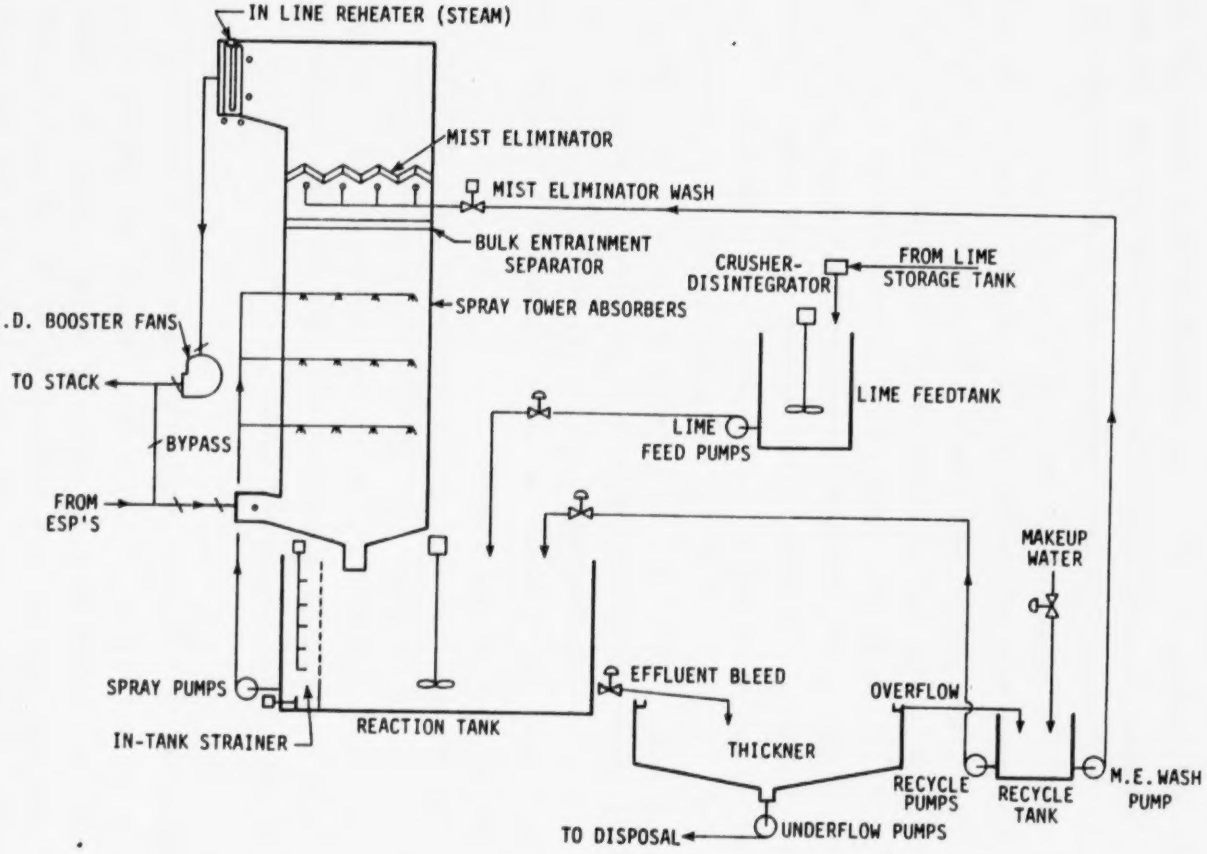
IN LINE REHEATER (STEAM)
MIST ELIMINATOR
MIST ELIMINATOR WASH
BULK ENTRAINMENT SEPARATOR
CRUSHER-DISINTEGRATOR
FROM LIME STORAGE TANK
I.D. BOOSTER FANS
SPRAY TOWER ABSORBERS
TO STACK
LIME FEEDTANK
LIME FEED PUMPS
BYPASS
FROM ESP'S
MAKEUP WATER
SPRAY PUMPS
EFFLUENT BLEED
OVERFLOW
REACTION TANK
IN-TANK STRAINER
THICKNER
RECYCLE PUMPS
RECYCLE TANK
M.E. WASH PUMP
TO DISPOSAL
UNDERFLOW PUMPS

Figure 3. Simplified process flow diagram of Cane Run 5 FGD system.

flows upward through each vertical spray tower at a rate of 133 m^3/s (261,000 acfm). Slurry is sprayed countercurrent to the flue gas flow from three levels of spray nozzles. The saturated, scrubbed gas stream then passes through a mist eliminator section situated at the top of each spray tower. Each mist eliminator consists of two stages of chevrons preceded by a bulk entrainment separator. Entrained droplets of moisture and slurry picked up by the gas stream as it passes through the spray towers are removed in the mist eliminator section.

Following passage through the mist eliminators, the cool, saturated gas stream exits the tower and turns 90 degrees and passes through in-line steam reheaters. Each module is equipped with four vertical rows of tubes which use steam to raise the temperature of the scrubbed gas stream approximately 22°C (40°F) above the water dewpoint as it leaves the spray tower. The treated gas stream then exits each spray tower at 142 m^3/s (300,000 acfm) and 74°C (166°F) and passes through an induced-draft booster fan. Each fan is provided to overcome the gas-side pressure drop encountered through the scrubber module and associated ductwork, which amounts to 1.4 kPa (5.5 in. H_2O). The reheated, scrubbed gas stream is then discharged to the atmosphere through the existing stack.

The ductwork and dampers provided with the FGD system allow gas to partially or totally bypass the scrubber modules. Seal-air louver dampers are installed at the inlet of each scrubber module and its associated bypass duct, and at the suction and discharge sides of each booster fan.

Slurry Handling--

Scrubbing slurry is delivered to each spray tower by one 1135 liter/s (18,000 gpm) spray pump. Spent scrubbing slurry falls by gravity to the bottom of each spray tower and drains to a common reaction tank with a liquid capacity of 1,779,000 liters (475,000 gal). The reaction tank is equipped with two top-entry agitators located at tank quarter points which keep the slurry solids in suspension. Mounted inside the tank is a perforated plate strainer located upstream of the spray pump suction lines. The strainer is equipped with an automatic back washer that prevents plugging and facilitates removal of the over-sized particles via the effluent bleed.

Fresh carbide lime slurry and makeup water are added directly to the reaction tank in order to maintain system chemistry and liquid inventory. The fresh carbide lime slurry regenerates the sulfur dioxide absorbent and precipitates waste solids which are removed from the slurry loop. The fresh makeup water added to the reaction tank is thickener overflow liquor supplemented by filtered river water. The waste solids which are precipitated in the reaction tank are removed by an effluent bleed line which gravity feeds to a thickener. The effluent bleed is operated so that a 10 percent solids slurry is continuously maintained in the reaction tank.

Solids Concentrating--

The effluent from the reaction tank is bled by gravity to the center well of a 34-m (110-ft) diameter thickener. At design operating conditions, 36 liters/s (568 gpm) of waste slurry is discharged to the thickener as a 10 percent solids stream. The thickener concentrates the waste slurry to a 25 percent solids sludge which is pumped from the bottom of the thickener to an on-site disposal pond. In order to aid the thickening process, a polyelectrolyte feeding system is provided to enhance precipitation within the thickener. This feeding system is similar to that provided for Cane Run 4 in that a flocculant is prepared, mixed, and aged and transferred directly to the thickener as a 0.5 percent solution. The 5 to 7 ppm concentration of flocculant which results in the thickener enhances the settling characteristics of the waste solids produced by the FGD system.

Clarified overflow from the thickener is transferred by gravity feed to a recycle tank (thickener overflow return tank) at a rate of 12 liters/s (196 gpm). Supernatant from the sludge disposal pond and fresh makeup water are also added to the recycle tank at a rate of 39 liters/s (420 gpm). This liquor is returned to the FGD system for use as mist eliminator wash water and to maintain system liquid inventory.

Lime Preparation and Handling Equipment--

The equipment provided for carbide lime slurry preparation is similar to that previously described for the Cane Run 4 FGD system. The carbide lime inventories are owned by LG&E and located on Airco, Inc.'s property five miles up river from the Cane Run plant. The absorbent is slurried to a 30 percent solids concentration and shipped by barge to the plant. The slurry is then transferred from the barges to the plant's main lime additive storage tanks by pumps. These tanks serve as storage vessels for the carbide lime slurry supplies required by all three FGD systems operating at the plant. The absorbent is then transferred to a crusher-disintegrator which supplies lime of proper consistency to the additive feed tank. The crusher-disintegrator removes any tramp solids or other foreign matter present in the slurry. The additive feed tank is an agitated hold tank with a 12-h retention time. This tank is located along side the reaction tank. Slurry is transferred from the additive feed tank to the reaction tank by centrifugal pumps through a recirculating circuit. At design conditions, 7.8 liters/s (124 gpm) of carbide lime is fed to the reaction tank as a 30 percent solids slurry. The flow of slurry from the additive feed tank to the reaction tank is controlled by slurry pH, outlet sulfur dioxide concentrations, and boiler load.

PROCESS DESIGN

Fuel

The Cane Run 4 and 5 FGD systems were designed to process flue gas resulting from the combustion of pulverized coal in the boilers. The coal is a high sulfur, bituminous grade which originates from the Star Mine of the Peabody Coal Company. Table 14 presents fuel specifications of the performance coal.

FGD Design Criteria

The design criteria of the Cane Run 4 and 5 FGD systems, including inlet and outlet gas conditions and removal efficiencies, are summarized in Table 15.

Scrubber Modules

The FGD systems installed on Cane Run 4 and 5 are each equipped with two modules. The Cane Run 4 scrubber module design consists of a vertical absorber tower preceded by a quencher and flooded elbow. The absorber tower is a single-stage mobile bed contactor which contains a fluid bed packing of solid spheres. The spheres are directed vertically through a circular path in the mobile bed contactor in order to maximize slurry contact surface area and remove the reaction products which build up on the spheres. Figure 4 presents a cutaway view of the mobile bed contactor, showing the arrangement of the internals and illustrating the actual sphere path.

The Cane Run 5 scrubber module design consists of a vertical spray tower absorber. Slurry is sprayed countercurrently to the flue gas flow from three levels of ceramic spray nozzles. Each elevation of sprays is composed of a grid of 28 nozzles uniformly spaced throughout the tower cross sections. The spray tower has a total contact zone of 5.5 m (18 ft) which provides a gas residence time of 2.25 seconds for sulfur dioxide removal.

Table 16 summarizes the design parameters and operating conditions of the Cane Run 4 and 5 scrubber modules.

Mist Eliminators

Each scrubber module is equipped with its own separate mist eliminator which is situated in the top portion of the absorber tower horizontal to the gas flow. For both systems, a chevron-type mist eliminator design is used. Originally, Cane Run 4 was

TABLE 14. SPECIFICATIONS OF CANE RUN PERFORMANCE COAL

	Cane Run 4	Cane Run 5
Fuel	Coal	
Grade	Bituminous	
Source	Kentucky	
Maximum consumption, Mg/h (tons/h)	76 (84)	79 (87)
Higher heating value, J/g (Btu/lb):		
Maximum	27,700 (11,900)	
Average	25,600 (11,000)	
Minimum	24,900 (10,700)	
Ultimate analysis, percent by weight:		
Carbon	62.93	
Hydrogen	4.18	
Oxygen	5.84	
Nitrogen	1.37	
Sulfur	4.14	
Chlorine	0.07	
Ash	14.10	
Moisture	9.59	

TABLE 15. DESIGN CRITERIA OF CANE RUN FGD SYSTEMS

Category	Inlet gas conditions		Outlet gas conditions[a]	
	Cane Run 4	Cane Run 5	Cane Run 4	Cane Run 5
Volume, m^3/s (acfm)	346 (734,000)	307 (650,000)	275 (583,000)	265 (562,000)
Temperature, °C (°F)	163 (325)	163 (325)	53 (127)	52 (126)
Weight, Mg/h (lb/h)	980.2 (2,161,000)	959.3 (2,115,000)	1,023 (2,256,000)	1,003 (2,212,000)
Density, kg/m^3 (lb/ft^3)	0.787 (0.491)	0.868 (0.054)	1.030 (0.065)	1.052 (0.066)
Sulfur dioxide, kg/h (lb/h), ng/J ($lb/10^6$ Btu)	6,309 (13,910) 2,885 (6.71)	5,652 (12,460) 2,885 (6.71)	947 (2,087) 434 (1.01)	844 (1,860) 434 (1.01)
Particulate matter, Mg/J ($lb/10^6$ Btu)	43 (0.1)	43 (0.1)	43 (0.1)	43 (0.1)
Sulfur dioxide removal efficiency, percent		85		85
Particulate matter removal efficiency, percent		0		0

[a] All values for outlet gas conditions given prior to reheat.

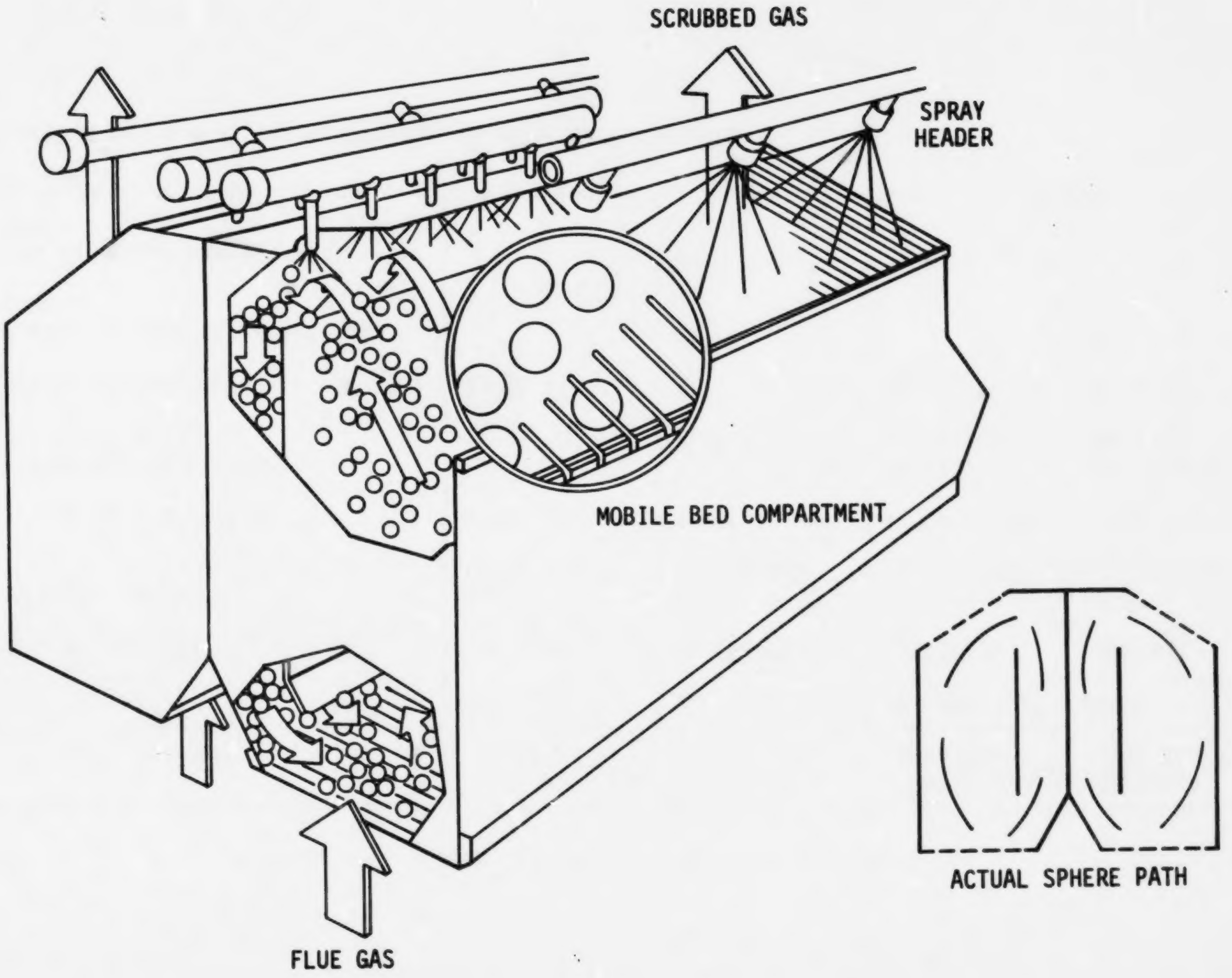
SCRUBBED GAS
SPRAY HEADER
MOBILE BED COMPARTMENT
ACTUAL SPHERE PATH
FLUE GAS

Figure 4. Cane Run 4 mobile bed contactor absorber and sphere path.

TABLE 16. DESIGN PARAMETERS AND OPERATING CONDITIONS OF CANE RUN SCRUBBER MODULES

	Cane Run 4	Cane Run 5
Number	2	2
Type	Quencher, flooded elbow, and mobile bed contactor	Spray tower
Configuration	Vertical	Vertical
Dimensions, m (ft)	6.1 x 6.1 x 8.4 (20 x 20 x 27.5)	8.1 x 9.4 (26.5 x 31)
Number of spray zones	2	3
Number of spray heads	5	3
Materials of construction:		
Quencher	Lined carbon steel	N/A
Flooded elbow	Lined carbon steel	N/A
Absorber	Lined carbon steel	316L stainless steel
Inlet flue gas volume, m^3/s (acfm)	173 (367,000)	154 (325,000)
Inlet flue gas temperature, °C (°F)	163 (325)	163 (325)
Flue gas velocity, m/s (ft/s)	3-4 (10-13)	2.1 (7)
Pressure drop, kPa (in. H_2O)	2.3 (9)	0.12 (0.5)
Liquid recirculation rate, liters/s (grm)	1112 (17,625)	1135 (18,000)
L/G, liters/m^3 (gal/10^3 acf)	8.6 (65)	7.4 (55)
Outlet flue gas volume, m^3/s (acfm)	138 (291,500)	133 (281,000)
Outlet flue gas temperature, °C (°F)	53 (127)	52 (126)

equipped with open-type centrifugal mist eliminators. These were replaced because of design and performance deficiencies. A proprietary mist eliminator design is used in Cane Run 5. This design consists of two stages of chevrons preceded by a precollector (bulk entrainment separator), as illustrated in Figure 5. Table 17 presents design conditions and operating parameters of the Cane Run 4 and 5 mist eliminators.

Reheaters

Each FGD system is equipped with its own set of reheaters which raise the temperature of the scrubbed gas stream above its dewpoint prior to discharge to the stack. Cane Run 4 is equipped with direct oil-fired reheaters situated in the discharge ducts at the base of the stack. Cane Run 5 is equipped with in-line carbon steel reheaters which use extraction steam as the heating medium. The Cane Run 4 reheaters were not installed as original equipment. They had to be added soon after system startup because of severe corrosion which occurred in the discharge ducts and stack. The Cane Run 5 reheaters are staggered vertical rows of finned-tubes situated in the horizontal discharge duct of each absorber. Table 18 summarizes the design parameters and operating conditions of the Cane Run 4 and 5 reheaters.

Pumps

Each FGD system is equipped with pumps which encompass the liquid circuit battery limits from lime preparation to waste solids disposal. Tables 19 and 20 summarize the design parameters and operating conditions of the major pumps installed on Cane Run 4 and 5, respectively.

Reaction Tanks

The Cane Run 4 and 5 FGD systems are equipped with external reaction tanks which provide slurry holdup to facilitate completion of chemical reactions, bleed of waste solids, and collection of fresh slurry and return water streams. Cane Run 4 is equipped

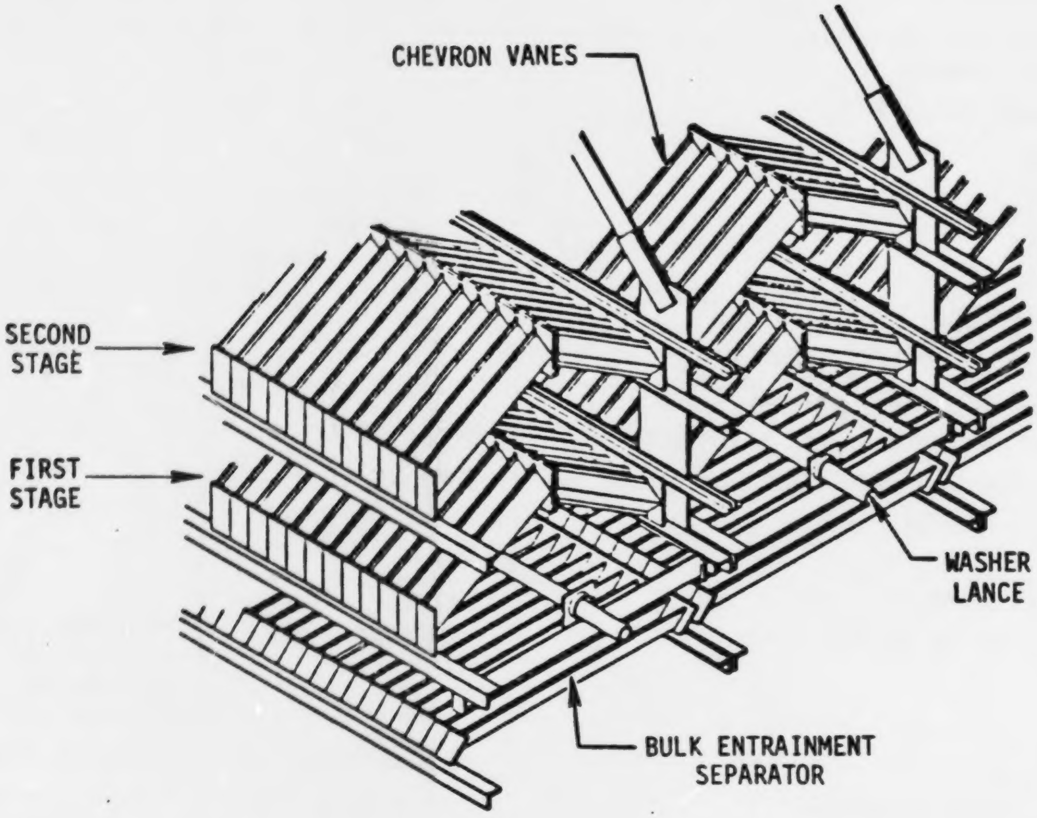
CHEVRON VANES
SECOND STAGE
FIRST STAGE
WASHER LANCE
BULK ENTRAINMENT SEPARATOR

Figure 5. Cane Run 5 mist eliminator design.

TABLE 17. DESIGN PARAMETERS AND OPERATING CONDITIONS OF CANE RUN MIST ELIMINATORS

Category	Cane Run 4	Cane Run 5
Total number	2	2
Number per module	1	1
Type	Chevron	Chevron
Configuration[a]	Horizontal	Horizontal
Shape	Z-shape, 120-degree bends	A-frame
Number of stages	2	3[b]
Number of passes per stage	3	2
Freeboard distance, m (ft)[c]	1.8 (6.0)	NA[d]
Distance between stages, m (ft)	NA	NA
Distance between vanes, cm (in.)	2.5-3.8 (1.0-1.5)	NA
Materials of construction	316L stainless steel	FRP
Wash system:		
Water source	River water	Blended water (river, pond supernanant, and thickerer overflow)
Point of collection	Makeup water tank	Recycle tank
Wash direction	Overspray and underspray	Overspray and underspray[e]
Wash frequency	Intermittent-2 min every 5 min	Intermittent-once every 24 hr.
Wash rate, liters/s (gpm)	5.0 (80)	32 (500)
Wash pressure, MPa (psig)	5.9 (70)	6.6 (80)
Superficial gas velocity, m/s (ft/s)	3.0 (10)	2.1 (7)
Pressure drop, kPa (in. H_2O)	0.12-0.30 (0.5-1.2)	0.12 (0.5)

[a] Relative to gas flow.

[b] Includes bulk entrainment separator.

[c] Distance between absorption zone and mist elimination section.

[d] Not available.

[e] Four water sprays (retractable soot blowers) are located between the bulk entrainment separator and first stage of cheverons. The blower lances rotate 360 degrees while traversing.

TABLE 18. DESIGN PARAMETERS AND OPERATING CONDITIONS OF CANE RUN REHEATERS

	Cane Run 4	Cane Run 5
Total number	2	2
Number per module	1	1
Type	Indirect, in-line	Direct combustion
Location	Discharge duct[a]	Discharge duct[b]
Heating medium	Steam	No. 2 fuel oil
Temperature elevation, °C (°F)	22 (40)	28 (50)
Heat exchangers:		N/A[c]
Number of rows	4	
Number of tube circuits	34	
Configuration	Vertical, staggered, spiral-finned tubes	
Tube size, cm (in.)	4.44 (1.75)	
Materials of construction	Carbon steel	

[a] Located in ducts as they enter the base of the stack.

[b] Located in ducts at the top of the absorber towers.

[c] Not applicable.

TABLE 19. DESIGN PARAMETERS AND OPERATING CONDITIONS OF CANE RUN 4 PUMPS

Service	Number	Manufacturer	Model	Materials		Drive	Performance[a]					Operation
				Casing	Impeller		Motor, kW (hp)	Capacity, liters/s (gpm)	Speed, rpm	Head, m (ft)	Solids, percent	
Slurry recirculation	6	Denver		Rubber-lined	Rubber-lined	Belt	244 (300)	371 (5875)	1000	36.6 (120)	10	6 operational, no spares
Slurry feed	2	Denver		Cast iron	Cast iron	Belt	7.5 (10)	12.6 (200)	1800	22.9 (75)	30	1 operational, 1 spare
Slurry bleed	4			Rubber-lined	Rubber-lined	Variable	5.6 (7.5)	13.9 (220)	NA[b]	18.3 (60)	10	2 operational, 2 spares
Thickener underflow	2	Robbins Meyers	2XNG 12H-CDR	Rubber-lined (neoprene)	Hi-A alloy	Variable	15 (20)	12.6 (200)	1800	35.1 (115)	25	1 operational, 1 spare
Thickener overflow	2	Goulds Morris	3196	Rubber-lined	Rubber-lined	Direct	18.7 (25)	38 (600)	1800	30 (100)	0	1 operational, 1 spare

[a] Per pump.
[b] Not available.

TABLE 20. DESIGN PARAMETERS AND OPERATING CONDITIONS OF CANE RUN 5 PUMPS

Service	Number	Type	Materials of construction	Performance			Operation
				Capacity, liters/s (gpm)	Solids, percent	pH	
Slurry recirculation	2	Centrifugal	Rubber-lined	1,100 (18,000)	10	9-10	2 operational, no spares
Slurry feed	2	Centrifugal, constant speed	NA[a]	7.8 (124)	30	11-12	2 operational, no spares
Thickener underflow	2	Positive displacement, variable speed	NA	15.6 (248)	25	9-10	1 operational, 1 spare
Recycle water	2	NA	NA	38.9 (616)	0	8-10	1 operational, 1 spare

[a] Not available.

with one rectangular reaction tank structure. This structure is divided into two discrete and separate reaction tanks by a partition running lengthwise through the tank structure. Each separate reaction tank services only one of the two scrubber modules. Further, each separate reaction tank is subdivided into three compartments by two partitions. Each compartment represents a separate reaction area and is equipped with its own top-entry agitator, pH monitor, and level control. Each separate reaction tank has a liquid capacity of approximately 1,703,000 liters (450,000 gal) which provides a retention time of approximately 25 minutes (a little more than 8 minutes per compartment). A simplified diagram of the Cane Run 4 reaction tank arrangement is provided in Figure 6.

Cane Run 5 is equipped with a single 1,779,000 liter (470,000 gal) reaction tank which is common to the scrubber modules. This capacity provides a slurry retention time of approximately 10 minutes. Two top-entry agitators located at tank quarter points keep the slurry solids in suspension. A strainer is mounted inside the reaction tank upstream of the spray pump suction lines. This in-tank strainer is essentially a perforated plate which protects the spray nozzles from plugging. An automatic back washer prevents the strainer from plugging. A simplified diagram of the in-tank strainer arrangement in the reaction tank is provided in Figure 7. Table 21 provides a summary of the design parameters and operating conditions of the Cane Run reaction tanks.

Thickeners

Each FGD system is equipped with a thickener which concentrates the solids in the spent slurry from 10 to 25 percent by weight prior to final disposal. Both thickening processes rely on flocculants to enhance solids settling characteristics. The liquor recovered by the thickeners is collected in surge tanks and returned to each system's respective reaction tank. Table 22 provides a summary of the design parameters and operating conditions of the Cane Run thickeners.

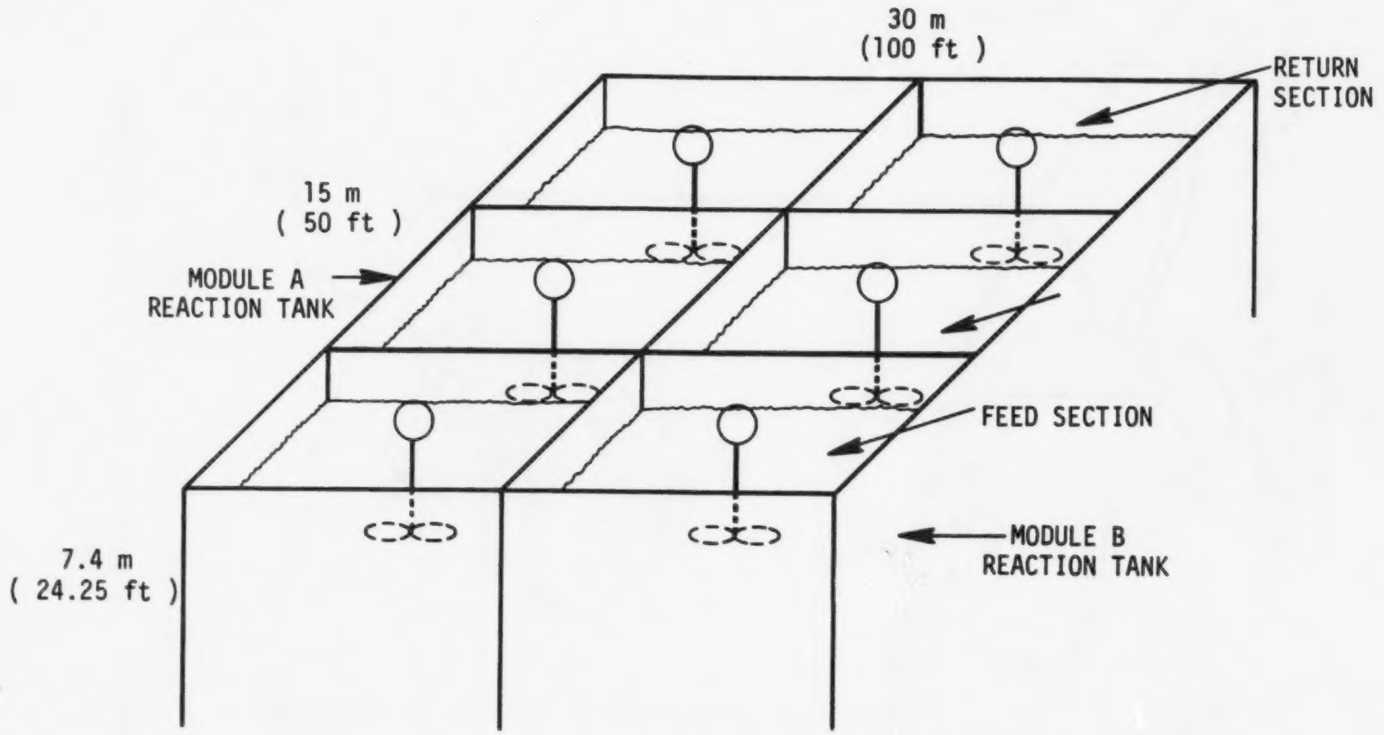
30 m
(100 ft)
RETURN SECTION
15 m
(50 ft)
MODULE A REACTION TANK
FEED SECTION
MODULE B REACTION TANK
7.4 m
(24.25 ft)

Figure 6. Arrangement of the Cane Run 4 reaction tank.

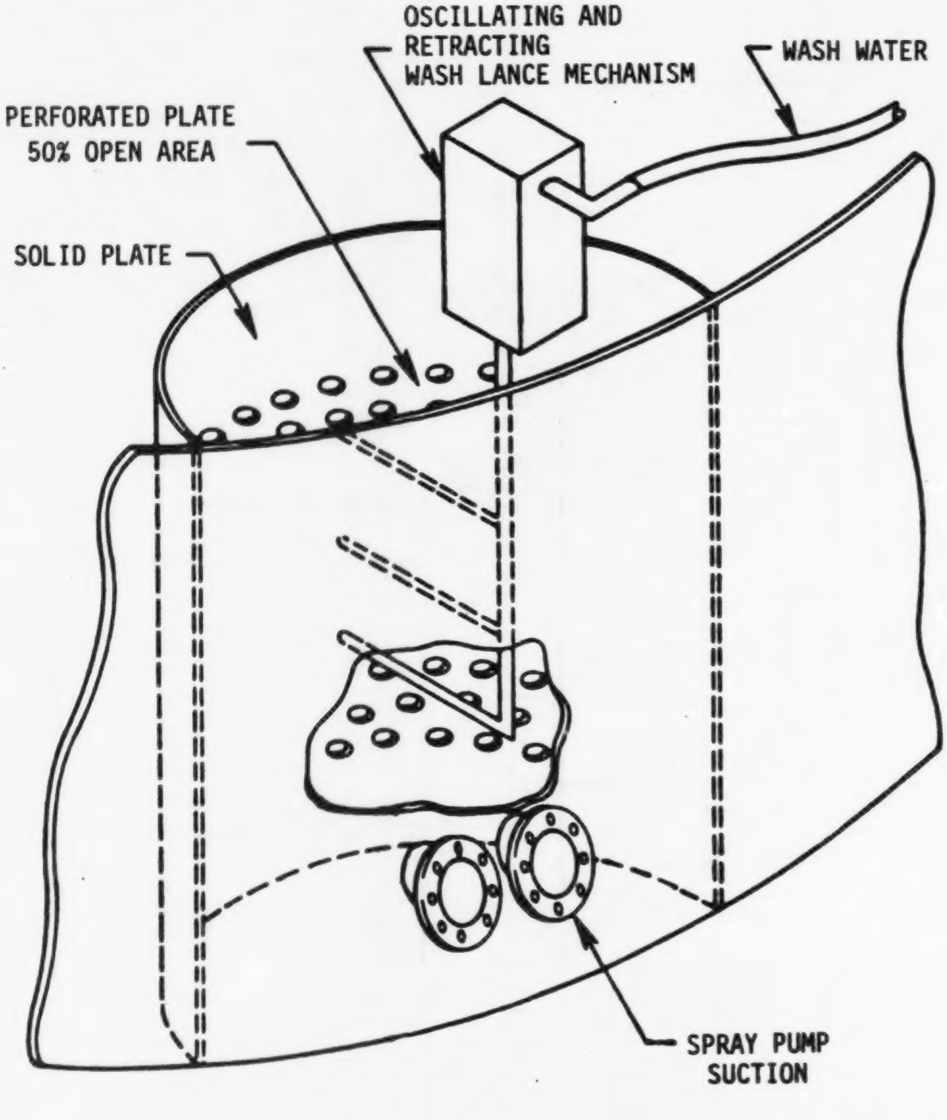
OSCILLATING AND
RETRACTING
WASH LANCE MECHANISM
WASH WATER
PERFORATED PLATE
50% OPEN AREA
SOLID PLATE
SPRAY PUMP
SUCTION

Figure 7. Cane Run 5 in-tank strainer arrangement.

TABLE 21. DESIGN PARAMETERS AND OPERATING CONDITIONS OF CANE RUN REACTION TANKS

	Cane Run 4	Cane Run 5
Number	2	1
Capacity, liters (gal)	1,703,000 (450,000)	1,779,000 (470,000)
Retention time, minutes	25	10
Materials of construction	Reinforced concrete	Rubber-lined carbon steel
Agitators:		
Number	3	2
Position	Top entry	Top entry
Motor, kW (hp)	37 (50)	56 (75)

TABLE 22. DESIGN PARAMETERS AND OPERATING CONDITIONS OF CANE RUN THICKENERS

	Cane Run 4	Cane Run 5
Number	1	1
Dimensions:		
Depth, m (ft)	4.3 (14)	NA[a]
Diameter, m (ft)	25.9 (85)	33.5 (110)
Materials of construction	Rubber-lined carbon steel	Rubber-lined carbon steel
Feed stream conditions:		
Thickener inlet:		
Flow, liters/s (gpm)	30 (475)	28 (450)
Solids, percent	10	10
pH	9-10	9-10
Thickener outlet:		
Flow, liters/s (gpm)	18.0 (285)	15.6 (248)
Solids, percent	25	25
pH	9-10	9-10
Thickener overflow:		
Flow, liters/s (gpm)	11.6 (185)	12.4 (196)
Solids, percent	0	0
pH	9-10	9-10

[a] Not available.

Process Control

Both Cane Run FGD systems are equipped with indicators, controls, and alarms which automatically monitor and control the operating conditions of the processes. Included are sulfur dioxide gas analyzers and temperature indicators for all gas inlet and outlet streams, magnetic flow meters for all liquid slurry streams, level indicators for all tanks, and pH and density meters for all reaction tanks.

Process chemistry is maintained and controlled primarily by monitoring slurry pH in the reaction tank and regulating the flow of additive to the tank as a function of this reading. For Cane Run 4, pH is measured in each section (compartment) of the reaction tank and automatically maintained at the control level. In the return section of the reaction tank, slurry pH is normally maintained between 4 and 6 as spent slurry from the scrubber is mixed and reacts with fresh carbide lime slurry. In the middle section of the reaction tank, slurry pH stabilizes as reactions started in the return section go to completion. Slurry pH is normally maintained between 8 and 9 in this section. In the feed section, all chemical reactions are completed and the slurry pH is trimmed to provide a pH level of 9.0 for slurry recirculated to the scrubber module. The pH levels measured in the reaction tank sections are characterized through a function generator. The function generator compares the output signals from the pH probes and corrects for any deviations in order to maintain a recycle slurry pH of 9.0 ± 0.1.

For Cane Run 5, pH is measured in the common reaction tank by one of two pH probes. Each probe is equipped with an ultrasonic cleaning device in order to assure dependable operation. An absorbent flow signal is provided by the pH probe which regulates the operation of a slurry control valve (C-E Invalco slurry control valve). This signal, along with the outlet sulfur dioxide and boiler load signals, regulates the flow of absorbent into the reaction tank in order to maintain a pH of 9 to 10 in the recycle slurry.

Carbide Lime

The additive requirements for both FGD systems are met through the use of carbide lime, a waste product from the manufacture of acetylene. The carbide lime inventories are obtained from Airco, Inc., an acetylene manufacturing firm located approximately 8 km (5 miles) up river from the Cane Run station. Table 23 provides a summary of the chemical composition of the carbide lime used at Cane Run.

PROCESS CHEMISTRY: PRINCIPAL REACTIONS

The chemical reactions involved in the Cane Run carbide lime FGD systems are highly complex. Although details are beyond the scope of this discussion, the principal chemical reactions are described in the paragraphs that follow.

The overall reactions involved in lime scrubbing can be expressed as:

$$CaO + SO_2 \longrightarrow CaSO_3$$

$$CaO + SO_2 + 1/2\ O_2 \longrightarrow CaSO_4$$

The various chemical steps involved in these overall reactions include absorption, neutralization, regeneration, oxidation, and precipitation.

The sulfur dioxide (SO_2) in the flue gas diffuses from the gas phase to the liquid phase. The absorbed sulfur dioxide reacts with water to form sulfurous acid (H_2SO_3).

$$SO_2 \uparrow \rightleftharpoons SO_2\ (aq.)$$

$$SO_2\ (aq.) + H_2O \rightleftharpoons H_2SO_3$$

In addition, carbon dioxide (CO_2) present in the flue gas is also absorbed into the liquid phase, forming carbonic acid (H_2CO_3).

$$CO_2 \uparrow \rightleftharpoons CO_2\ (aq.)$$

$$CO_2\ (aq.) + H_2O \rightleftharpoons H_2CO_3$$

TABLE 23. CHEMICAL COMPOSITION OF CANE RUN CARBIDE LIME[a]

Compound	Percent by weight
$Ca(OH)_2$	92.50
CaO[b]	70.01
$CaCO_3$	1.85
SiO_2	1.50
Al_2O_3	1.40
Fe_2O_3	0.20
MgO	0.07
S	0.15
P	0.01
C[c]	0.25
Undetermined	2.07

[a] Source: Airco catalog (1969).

[b] Available calcium oxide.

[c] Free carbon.

The sulfurous acid formed during absorption in the scrubber is neutralized by dissolved alkali [sulfite ($SO_3^{=}$) and bicarbonate (HCO_3^{-}) ions] present in the scrubbing slurry.

$$H_2SO_3 + SO_3^{=} \rightleftharpoons 2HSO_3^{-}$$

$$H_2SO_3 + HCO_3^{-} \rightleftharpoons HSO_3^{-} + H_2CO_3$$

During the absorption and neutralization steps, some oxidation occurs in the system which results in the presence of sulfate ion ($SO_4^{=}$) in the scrubbing liquor. This also occurs to a lesser extent by gas phase oxidation of sulfur dioxide and its subsequent ionization in the scrubbing liquor.

$$2\ SO_2\uparrow + O_2\uparrow \rightleftharpoons 2SO_3\uparrow$$

$$2\ SO_3\uparrow \rightleftharpoons 2SO_3\ (aq.)$$

$$2\ SO_3\ (aq.) + 2H_2O \rightleftharpoons 2H_2SO_4$$

$$2\ H_2SO_4 \rightleftharpoons 2H^{+} + 2SO_4^{=}$$

However, the liquid-phase oxidation of sulfite and bisulfite (HSO_3^{-}) accounts for the majority of sulfate formed in the system.

$$2\ HSO_3^{-} + O_2\ (aq.) \rightleftharpoons 2SO_4^{=} + 2H^{+}$$

$$2\ SO_3^{=} + O_2\ (aq.) \rightleftharpoons 2SO_4^{=}$$

The spent scrubbing slurry, which contains primarily soluble bisulfite, is discharged to the reaction tank where fresh carbide lime slurry [$Ca(OH)_2$] reacts and neutralizes the reaction products formed in the scrubber.

$$Ca(OH)_2 + 2HSO_3^{-} \rightleftharpoons Ca^{++} + 2SO_3^{=} + 2H_2O$$

$$Ca(OH)_2 + 2H_2CO_3 \rightleftharpoons Ca^{++} + 2HCO_3^{-} + H_2O$$

The dissolution of carbide lime in the reaction tank results in alkali regeneration and the precipitation of reaction products. This latter step occurs as a result of an increase in scrubbing liquor pH and calcium ion (Ca^{++}) concentration caused by carbide lime dissolution. The reaction product formed in the scrubbing process is a mixed crystal of calcium sulfite and calcium sulfate.

$$Ca^{++} + (1-X)SO_3^{=} + (X)SO_4^{=} + 1/2\ H_2O \rightleftharpoons$$

$$[(1-X)\ CaSO_3 \cdot (X)\ CaSO_4] \cdot 1/2\ H_2O \downarrow$$

The calcium sulfite/calcium sulfate formed is a solid solution in which the value of X (the ratio of sulfate to total sulfur in the solution) is about 0.16. Thus, any sulfate formed in the scrubbing process is removed in the coprecipitate. This will occur as long as the maximum sulfite oxidation in the process is 16 percent. Levels of oxidation well below the maximum limit have been experienced at Cane Run (and Paddy's Run) because of the presence of oxidation inhibitors in the carbide lime.[1]

SECTION 4

FGD SYSTEM PERFORMANCE

OPERATING HISTORY AND PERFORMANCE

Cane Run 4

The Cane Run 4 FGD system was first placed in service on August 7, 1976. After approximately 2 weeks of operation a number of major operating problems were encountered which limited system capacity, service time, and removal efficiency. The major initial problem involved excessive pressure drop across the system. This limited the system's maximum gas treating capacity to approximately 150 MW of equivalent electrical generating capacity. This problem, in addition to problems encountered with the system's spray nozzles and recirculation pumps, resulted in a number of various modifications which commenced in early September 1976 and continued intermittently throughout the remainder of the year. These modifications enabled the system to operate at full load conditions and achieve an operability of 90 percent for the August to December 1976 period. Sulfur dioxide removals, however, remained below the design level of 85 percent.

From early January until early March 1977, the system was operated intermittently because of curtailment of carbide lime supplies. This occurred because of the severe winter weather conditions which caused the Ohio River to freeze, thus suspending all barge deliveries of carbide lime to the station. During this period, the system was operated in a slurry-recycling mode (without flue gas) to prevent freeze-ups in the associated piping. At two week intervals flue gas was passed through the system in order to warm-up the recycling slurry.

Lime slurry supplies were reestablished in early March and the system was returned to service from mid-March to mid-April 1977 (operability of approximately 90 percent). During the period, the system was operated in various test modes in anticipation of a basic redesign of the system. System redesign was required because of unsatisfactory sulfur dioxide removals, inefficient mist elimination, and lining failures in the outlet ducts and stack. From April 18, 1977, to July 17, 1977, major modifications were made in order to improve system performance with respect to the problem areas mentioned above. Following its return to service, the system successfully completed compliance testing on August 3 and 4, 1977. Since the completion of these major modifications, system operability has averaged approximately 90 percent for the past two years. Periods of system inactivity have resulted primarily from external conditions such as severe winter conditions, a coal strike, boiler and turbine repairs, and scheduled annual unit overhauls.

A summary of the performance of the Cane Run 4 FGD system is provided in Table 24.

Cane Run 5

The Cane Run 5 FGD system was first placed in service on December 28, 1977. Immediately following initial startup, the FGD system was taken out of service in order to complete construction and correct some problems encountered during startup. On March 24, 1978, the FGD system was returned to service. During the course of the months that followed, various performance tests were conducted in order to demonstrate contractual guarantees and compliance with air emission regulations. These tests were successfully completed by mid-July 1978.

The operability of the FGD system averaged approximately 83 percent for the period of April through December 1978. During the first 9 months of 1979, the FGD system's operability has averaged approximately 80 percent. Although some downtime can be attributed to severe winter weather conditions which caused

TABLE 24. CANE RUN 4 FGD SYSTEM PERFORMANCE SUMMARY: AUGUST 1976 TO SEPTEMBER 1979

Date	Period hours	Boiler hours	FGD hours	Operability	Utilization
Aug. 1976	744	740	666	90.0	90.0
Sep. 1976	720	720	650	90.0	90.0
Oct. 1976	744	600	540	90.0	73.0
Nov. 1976	720			95.0	
Dec. 1976	744			90.0	
Jan. 1977	744	Shut down because of severe winter weather conditions			
Feb. 1977	672	Shut down because of severe winter weather conditions			
Mar. 1977	744	432	358	83.0	48.1
Apr. 1977	720	Shut down because of FGD system modifications			
May 1977	744	Shut down because of FGD system modifications			
June 1977	720	Shut down because of FGD system modifications			
July 1977	744	360	324	90.0	43.6
Aug. 1977	744	657	588	94.0	93.0
Sep. 1977	720	529	524	99.0	99.0
Oct. 1977	744	677	662	98.0	89.0
Nov. 1977	720	483	453	94.0	63.0
Dec. 1977	744	715	608	85.0	82.0
Jan. 1978	744	742	494	67.0	67.0
Feb. 1978	672	Shut down because of coal shortage due to strike			
Mar. 1978	744	264	249	94.0	34.0
Apr. 1978	720	303	303	100.0	47.0
May 1978	744	352	115	35.0	12.0
June 1978	720	720	715	99.0	99.0
July 1978	744	687	678	99.0	91.0
Aug. 1978	744	744	701	94.0	94.0
Sep. 1978	720	138	138	100.0	19.0
Oct. 1978	744	Shut down because of boiler tube repairs			
Nov. 1978	720	432	420	97.0	58.0
Dec. 1978	744	Shut down because of turbine and boiler tube repairs			
Jan. 1979	744	Shut down because of turbine and boiler tube repairs			
Feb. 1979	672	Shut down because of turbine and boiler tube repairs			
Mar. 1979	744	Shut down because of turbine and boiler tube repairs			
Apr. 1979	720	Shut down because of turbine and boiler tube repairs			
May 1979	744	Shut down because of turbine and boiler tube repairs			
June 1979	720	266	123	46.2	17.1
July 1979	744	701	692	99.0	92.0
Aug. 1979	744	744	664	89.0	89.0
Sep. 1979	720	Shut down because of boiler tube repairs			

interruptions of lime deliveries to the plant, the majority of FGD system inactivity has been caused by reheater tube failures.

A summary of the performance of the Cane Run 5 FGD system is provided in Table 25.

PROBLEMS AND SOLUTIONS

Problems were encountered with both FGD systems during and subsequent to their initial startup. In the case of Cane Run 4, the problems were so severe as to require a 4-month shutdown for a basic redesign of the FGD system. The major operating problems encountered by both FGD systems, as well as solutions and system modifications, are described for each system in the paragraphs that follow.

Cane Run 4

As previously mentioned, the Cane Run 4 FGD system encountered a number of major operating problems shortly after initial startup. Pressure drops in excess of design were encountered which limited the system's maximum gas treating capacity to approximately 150 MW of equivalent electrical generating capacity. This was attributed to gas flow distribution problems in the ducts and mist eliminators. As such, gas turning vanes were installed in the quenchers, flooded elbows, just below the mobile bed contactors, just above the mist eliminators, and at the base of the stack. Sections of the original radial vane mist eliminators were cut out and removed.

These modifications remedied the excessive pressure drop problem. However, subsequent problems were soon encountered with solids carryover from the scrubbers because of the reduction in mist elimination efficiency. In addition, sulfur dioxide removal efficiencies well below guarantee levels were measured at full load. With respect to sulfur dioxide removals, values of 90 to 92 percent were achieved for boiler loads up to 100 MW. However, as boiler load increased the sulfur dioxide removals decreased to 82 to 85 percent for 120 MW and 70 percent for full load.

TABLE 25. CANE RUN 5 FGD SYSTEM PERFORMANCE SUMMARY: DECEMBER 1977 TO SEPTEMBER 1979

Date	Period hours	Boiler hours	FGD hours	Operability	Utilization
Dec. 1977	744	Shut down for completion of construction			
Jan. 1978	744	Shut down for completion of construction			
Feb. 1978	672	Shut down for completion of construction			
Mar. 1978	744	Shut down for completion of construction			
Apr. 1978	720	699	648	97.0	90.0
May 1978	744	432	364	84.0	49.0
June 1978	720	685	590	86.0	82.0
July 1978	744	632	506	80.0	68.0
Aug. 1978	744	540	464	86.0	62.0
Sep. 1978	720	609	485	80.0	67.0
Oct. 1978	744	530	509	96.0	71.0
Nov. 1978	720	253	238	94.0	33.0
Dec. 1978	744	654	302	46.2	40.6
Jan. 1979	744	693	467	67.4	62.8
Feb. 1979	672	477	337	70.6	50.1
Mar. 1979	744	596	428	71.8	57.5
Apr. 1979	720	360	357	99.2	49.6
May 1979	744	433	365	84.3	49.1
June 1979	720	544	419	77.0	58.2
July 1979	744	583	420	72.0	56.0
Aug. 1979	744	613	540	88.0	73.0
Sep. 1979	720	469	392	84.0	54.0

In analyzing the sulfur dioxide removal problem, LG&E and AAF determined that the system's original design L/G ratio of 5.2 liters/m^3 (39 gal/1000 acf) was insufficient. In an attempt to increase L/G, the spare recirculation pump provided for each scrubber module was placed in service. By coupling the spare pump into the slurry circuit of each scrubber, the L/G should have increased to approximately 8.6 liters/m^3 (65 gal/1000 acf). Although each recirculation pump has a rated capacity of approximately 370 liters/s (5875 gpm), a total flow increase of only 31 to 38 liters/s (500 to 600 gpm) was realized. This occurred because of excessive pressure drops across the spray headers. To correct this problem, the original plastic spinner-vane spray nozzles were replaced with a different nozzle design constructed of ceramic. This modification decreased pressure drop, permitting the slurry flow rate to increase to a level which approached an equivalent L/G of approximately 8 liters/m^3 (60 gal/1000 acf). Although sulfur dioxide removal levels improved, they still remained below satisfactory levels when the unit was operated at full load.

Because of these continuing problems, LG&E and AAF performed a number of major modifications to the system's design during a 4-month outage in the spring and summer of 1977. These modifications essentially amounted to a basic redesign of the system in order to increase sulfur dioxide removal, improve mist eliminator efficiency, and correct a number of material failures with the coatings applied to the outlet ducts and stack. These modifications are briefly summarized in the following:

1. A new spray header system was installed above the original mobile bed contactor spray headers. Underbed sprays were also added just below the mobile bed contactor. These changes improved the distribution of gas flowing through the mobile bed, improved the circulation of the balls through the mobile bed contactor compartments, and increased the L/G of the system to approximately 8.6 liters/m^3 (65 gal/1000 acf). This has provided a superior slurry/gas contacting mechanism which has contributed to improved sulfur dioxide removal efficiency.

2. In conjunction with a new spray header arrangement, the pH/slurry feed control system was significantly modified in order to improve chemical control and sulfur dioxide removal. The pH meters, which are dip-type probes situated in the reaction tank compartments, were replaced with more reliable units. The original meters tended to drift 3 minutes after calibration. The control level of the pH of the scrubbing slurry was increased from approximately 8.5 to 9.0.

3. Each scrubber module was originally equipped with an open-type centrifugal mist eliminator which was located in the top of the absorber tower downstream of the mobile bed contactor compartments. These mist eliminators consisted of stationary, widely-spaced, curved vanes which directed the slurry droplets against the mist eliminator shell. The flue gases then entered a "necked-out" open cylindrical area where a reduction in flue gas velocity caused the remaining droplets present in the gas stream to drop out and drain downward along the mist eliminator shell through a drain box and into the drain lines of each absorber tower. Problems associated with excessive pressure drop across these mist eliminators required sections of the radial-vane assembly to be removed. This subsequently decreased mist eliminator efficiency and caused an increase in the slurry solids carried over in the scrubbed gas stream. The radial vane assembly was then removed entirely from each absorber tower by cutting 4-cm (18-in.) holes into the top of the assembly and replacing it with 2 stages of 3-pass chevron mist eliminators. The wash water spray system associated with the centrifugal design was also replaced with a system compatible with the chevron design. Since these changes were completed, mist eliminator efficiency has improved and the chevrons have operated without any buildup of solids on the vanes.

4. Direct oil-fired reheat burners were installed in the exit ductwork as it enters the stack. These burners fire No. 2 fuel oil and the combustion products are mixed with the scrubbed gas stream to raise its temperature a maximum of 28°C (50°F). Originally, reheat was not included in this system. However, this "wet stack" approach, coupled with the initial problems associated with low sulfur dioxide removal and mist elimination inefficiency, ultimately contributed to the lining failures which occurred in the mist eliminator shells, discharge ducts, and stack.

5. As indicated above, the linings used in the mist eliminators, discharge ducts, and stack were severely corroded and required replacement. A Carboline liner was originally used on the mist eliminator shells and discharge ducts. This material was severely blistered and was replaced with Plasite 4005. Acid brick was originally used to line the concrete shell of the unit's existing stack. Failure of this material required all the brickwork in this 76-m (250-ft) stack to be replaced with Precrete G-8 spray-applied to wire mesh.

These major modifications were originally projected to require only 2 months for completion during the annual unit overhaul. However, the lengthy installation of the new lining materials, especially the Plasite 4005, required a 2-month extension for completion of this work.

On July 17, 1977, the FGD system was returned to service. On August 3 and 4, 1977, the system successfully completed a series of performance tests conducted by EPA. Since that time, the FGD system has operated at a high level of mechanical reliability and has been continuously in compliance. The only problem of any major proportion which has been encountered since restart involves the operation of the guillotine dampers which are situated at the inlet, outlet, and bypass ducts of each scrubber module. The problem with the operation of these dampers involves their inability to track smoothly without excessive sticking during raisings and lowerings. Minor modifications to the guillotine gate assemblies have since corrected this problem.

Cane Run 5

The initial and subsequent operation of the Cane Run 5 FGD system was also accompanied by problems. However, unlike Cane Run 4, most of these problems were of a minor variety normally encountered during FGD system startup. Some of the problems and solutions worth noting are discussed in the paragraphs that follow.

During startup, operating difficulties with the louver dampers were encountered which at first were attributed to undersized drives. Subsequent analysis revealed, however, that the difficulties were related to a combination of linkage adjustment, sealing strip alignment, and lubrication deficiencies. During periods when one or both scrubber modules were bypassed, a small amount of gas leakage occurred that limited access to the modules. This was caused by a low positive flue gas pressure of approximately 0.1 kPa (0.5 in H_2O) or less which was produced at the base of the stack.

In order to correct this problem, adjustments were made to the linkages, sealing strips, and lubrication systems. In addition, a damper seal air system was added which provides seal air to each louver damper in the system. This insured 100 percent flue gas sealing during bypass and permitted safe access to the scrubber modules for inspection and maintenance.

The recirculation pumps encountered some minor difficulties in the form of scoring of the shaft sleeves shortly after startup. These failures were the result of low seal water flow to the packing glands. The original glands were designed for low flows during low load operations in order to minimize the dilution of slurry solids by the fresh water used for pump seals. This design, however, was sensitive to minor flow variations caused by the straining of river water for use as pump seal water. Becuase of these problems the following remedial action was taken: (1) the scored shaft sleeves were replaced and (2) the original glands were replaced with standard glands of higher flow rates in order to accommodate the flow variations. This modification improved component reliability and did not present any problems with respect to solids control in the recycled scrubbing slurry.

The reagent feed/pH control system has performed as designed with the exception of reliable measurement of reaction tank pH. The pH of the recirculated slurry as it entered the absorber spray headers was higher than measured by the pH probe in the reaction tank. As such, excessive absorbent feed rates resulted in a higher reagent consumption and lower reagent utilization than had been designed. Although stable control of slurry pH was maintained, the probe was relocated in order to more accurately reflect the pH of the scrubbing slurry as it entered the absorbers, thus preventing excessive feed of absorbent to the system.

The most significant problem encountered by the system to date has involved the operation of the reheaters. These reheaters are in-line, spiral-finned, carbon steel heat exchangers which use extraction steam as the heating medium. Leaks in both bundles were detected shortly after startup and were repaired on an individual basis. Analysis of these failures revealed defective welds in the unfinned tubing at the tube return bends. Although repairs were successfully completed on an individual basis, a complete rework of the affected shop welds was performed to insure no weak spots remained.

Other minor problems which were encountered during startup included hardware malfunctions, incorrect instrument calibration, and plugging from construction debris. The startup of the auxillary equipment such as pumps, agitators, booster fans, and the thickener went routinely.

REMOVAL EFFICIENCIES

As previously mentioned, both FGD systems successfully completed performance testing to demonstrate contractual guarantees and compliance with sulfur dioixde air emission regulations. Both systems are designed to remove 85 percent of the inlet sulfur dioxde and comply with the Federal new source performance standard (NSPS) of 516 ng/J (1.2 lb/10^6 Btu)* when 4 percent sulfur coal is burned in the boilers. The results of these performance tests, as well as other emission test results and continuous monitoring data, are summarized in the following paragraphs.

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*The Federal NSPS of the Clean Air Act of 1971.

Cane Run 4

As previously mentioned, the FGD system was not able to achieve design sulfur dioxide removal efficiencies when operating at full load during initial startup. Prior to the major modification and basic system redesign work which commenced in April 1977, a 7- to 10-day test run was completed (commenced on March 14, 1977) in which "black lime"* was used as the absorbent. During this test, sulfur dioxide removals averaged approximately 95 percent.

On August 3 and 4, 1977, the FGD system underwent and successfully completed performance testing. The testing, which was performed by EPA personnel, indicated that sulfur dioxide removal efficiencies were in the 86 to 89 percent range when coal of 3.3 to 3.4 percent sulfur was burned in the boiler at full load. This corresponded to an outlet emission level of approximately 334 ng/J (0.8 lb/10^6 Btu). These tests were repeated one month later and confirmed that the unit was in compliance.

From mid-1977 to early 1978, the Emissions Standards and Engineering Division of the Office of Air Quality Planning and Standards of the U.S. EPA conducted a program to acquire sulfur dioxide monitoring data in support of revisions to the NSPS for fossil-fuel-fired steam-electric generators. Data from five different utility FGD-equipped boilers were obtained at this time. The results were reduced and published by EPA in two volumes in August 1978.[2,3]

One of the five sites from which data were obtained was Cane Run 4. Sulfur dioxide and oxygen gas concentrations were continuously monitored by gas analyzers placed upstream (between the

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*A form of carbide lime from the carbide slag operation which contains 2 to 4 percent magnesium oxide.

ESP's and booster fans) and downstream (between the reheaters and stack) of the scrubber modules. Gas samples were taken every 15 minutes and this data was statistically analyzed for consecutive 1-hour, 3-hour, 8-hour, and 24-hour averages. After each 30-day period of average interval data, a statistical summary was prepared. Using these 30-day statistical summaries, an overall summary of the sulfur dioxide monitoring data for the period of July 21, 1977, to December 23, 1977, was assembled by PEDCo Environmental and is presented in Table 26.

As indicated by the data in this table, the total system sulfur dioxide removal efficiencies averaged 83.2 to 83.3 percent for Cane Run 4 for the four different averaging periods analyzed during this program. These values compare with the system's design sulfur dioxide removal efficiency of 85 percent.

Cane Run 5

From mid-May to mid-July 1978, a series of performance tests were conducted in order to demonstrate contractual guarantees and compliance with air emission regulations. In mid-May and early June, particulate and sulfur dioxide emission measurements were completed. However, because of procedural and data analysis errors, the sulfur dioxide emission measurements had to be repeated in mid-July. A summary of the particulate and sulfur dioxide emission tests are provided in Tables 27 and 28.

The particulate emissions were measured simultaneously at the outlet of the ESP (scrubber inlet) and at the inlet of the stack (scrubber outlet) in accordance with EPA Reference Method 5. The tests were run at or near full load conditions and during some of the tests high inlet particulate loadings were created (for test purposes only) by de-energizing the final field of the ESP's. The results summarized in Table 27 indicate that the scrubbers were able to provide substantial secondary particulate control. For example, with the unit operating at full load and the ESP fully energized (test results for May 22 and June 1,

TABLE 26. SUMMARY OF CANE RUN 4 SULFUR DIOXIDE CONTINUOUS MONITORING DATA: JULY 21 TO DECEMBER 23, 1977[a]

Averaging period, hours	Sulfur dioxide concentration		Total system removal efficiency, percent
	Inlet ng/J (lb/10^6 Btu)	Outlet ng/J (lb/10^6 Btu)	
1	2452 (5.702)	413 (0.960)	83.2
3	2455 (5.709)	413 (0.960)	83.2
8	2447 (5.691)	410 (0.954)	83.3
24	2434 (5.669)	410 (0.955)	83.2

[a] The data which appears in this table represents a summary prepared by PEDCo Environmental of the individual monthly statistical summaries prepared and published by EPA.

TABLE 27. SUMMARY OF CANE RUN 5 PARTICULATE EMISSION TESTS: MAY 19 TO JUNE 7, 1978

Date	Unit load, MW (net)	Particulate loading, ng/J (lb/10^6 Btu)		Removal efficiency, %
		Inlet	Outlet	
May 19, 1978	173	104.5 (0.243)	26.23 (0.061)	74.9
May 27, 1978	194	53.32 (0.124)	21.50 (0.050)	59.7
June 1, 1978	188	38.27 (0.089)	19.35 (0.045)	49.4
June 7, 1978	188	117.8 (0.274)	15.05 (0.035)	87.2
June 7, 1978	188	143.2 (0.333)	17.63 (0.041)	87.7

TABLE 28. SUMMARY OF CANE RUN 5 SULFUR DIOXIDE EMISSION TESTS: JULY 10 TO 14, 1978

Date	Unit load, MW (net)	Sulfur dioxide, ng/J ($lb/10^6$ Btu)		Removal efficiency, %
		Inlet	Outlet	
July 10, 1979	166-186	2481.1 (5.77)	210.7 (0.49)	91.5
July 11, 1979	106-176	2730.5 (6.35)	245.4 (0.58)	90.9
July 14, 1979	190	2777.8 (6.46)	516.0 (1.20)	81.4

1978), the spray towers removed approximately 50 to 60 percent of the inlet particulate. With the ESP partially de-energized, these removals increased to approximately 75 to 88 percent. As expected, the collection efficiency of the spray towers increased as the loadings of the inlet particulate increased.

The sulfur dioxide emissions were measured in accordance with EPA Reference Method 5. The results presented in Table 28 for data obtained on July 10 and 11 show average sulfur dioxide removal efficiencies exceeding 90 percent over a unit load range of 106 to 186 MW (net). Data obtained on July 14 indicates that the system's sulfur dioxide removal efficiency dropped appreciably (81.4 percent) as the unit's net output began to appreciably exceed maximum continuous operating capacity and approach maximum peak load. However, subsequent to the testing of July 14, it was discovered that a malfunction of the sulfur dioxide continuous gas analyzer resulted in a reduction of the feed rate of fresh carbide lime slurry to the system. Although slurry pH provides primary control of lime slurry feed rate to the system, flue gas sulfur dioxide provides a "trim" to the amount of slurry entering the system. As such, the gas analyzer malfunction caused an abnormally low spray liquor pH which resulted in a decreased sulfur dioxide removal efficiency.

Based on the results of the sulfur dioxide emission tests, it was concluded that the FGD system met all contractual guarantees and compliance requirements. The system demonstrated that an average outlet sulfur dioxide concentration of 516 ng/J (1.2 lb/10^6 Btu) can be achieved and that the system can remove 85 percent of the inlet sulfur dioxide over the entire unit load range.

FUTURE OPERATIONS

In addition to Cane Run 4 and 5, LG&E has recently started up the FGD system installed on Cane Run 6. This FGD system is part of a demonstration project sponsored by EPA in order to demonstrate the soda ash/lime dual alkali FGD process on a commercial-sized coal-fired utility boiler. The system, which is supplied by CEA/ADL, comprises two parallel absorber towers, soda ash and carbide lime storage and preparation equipment, a thickener and rotary drum vacuum filters, and a series of absorbent regeneration reactors. Sulfur dioxide absorption is accomplished by a clear liquor of soluble sodium salts containing sodium hydroxide, sodium carbonate, sodium sulfite, and sodium sulfate. A continuous bleed stream of spent scrubbing liquor is drawn from the absorber recirculation loop and is sent to the absorbent regeneration reactors. A reactor train of two reactor stages receives the spent scrubbing liquor. Hydrated carbide lime is added to the reactor in order to neutralize the bisulfite acidity in the bleed stream and react with the sodium sulfite and sulfate present in the liquor to produce sodium hydroxide. These reactions precipitate mixed calcium sulfite and sulfate solids which are concentrated in the thickener and vacuum filters to a 55 to 70 percent insoluble solids filter cake and disposed in an onsite sludge pond.

Construction of the FGD system was completed in early 1979 and initial startup occurred in April 1979. To date, the FGD system is still in its shakedown and debugging phase of operation. Performance testing to demonstrate contractual guarantees and compliance with air pollution regulations has not as yet been performed. Following the successful completion of these tests, the system will operate through a 1-year test program to demonstrate overall performance with respect to sulfur dioxide removal, reagent consumption, power consumption, water balance, chemical- and mechanical-related problems, waste solids properties, availability and reliability, and capital and annual costs.

A simplified process flow diagram of the Cane Run 6 dual alkali FGD system is presented in Figure 8. The design basis, operating conditions, and performance guarantees for the FGD

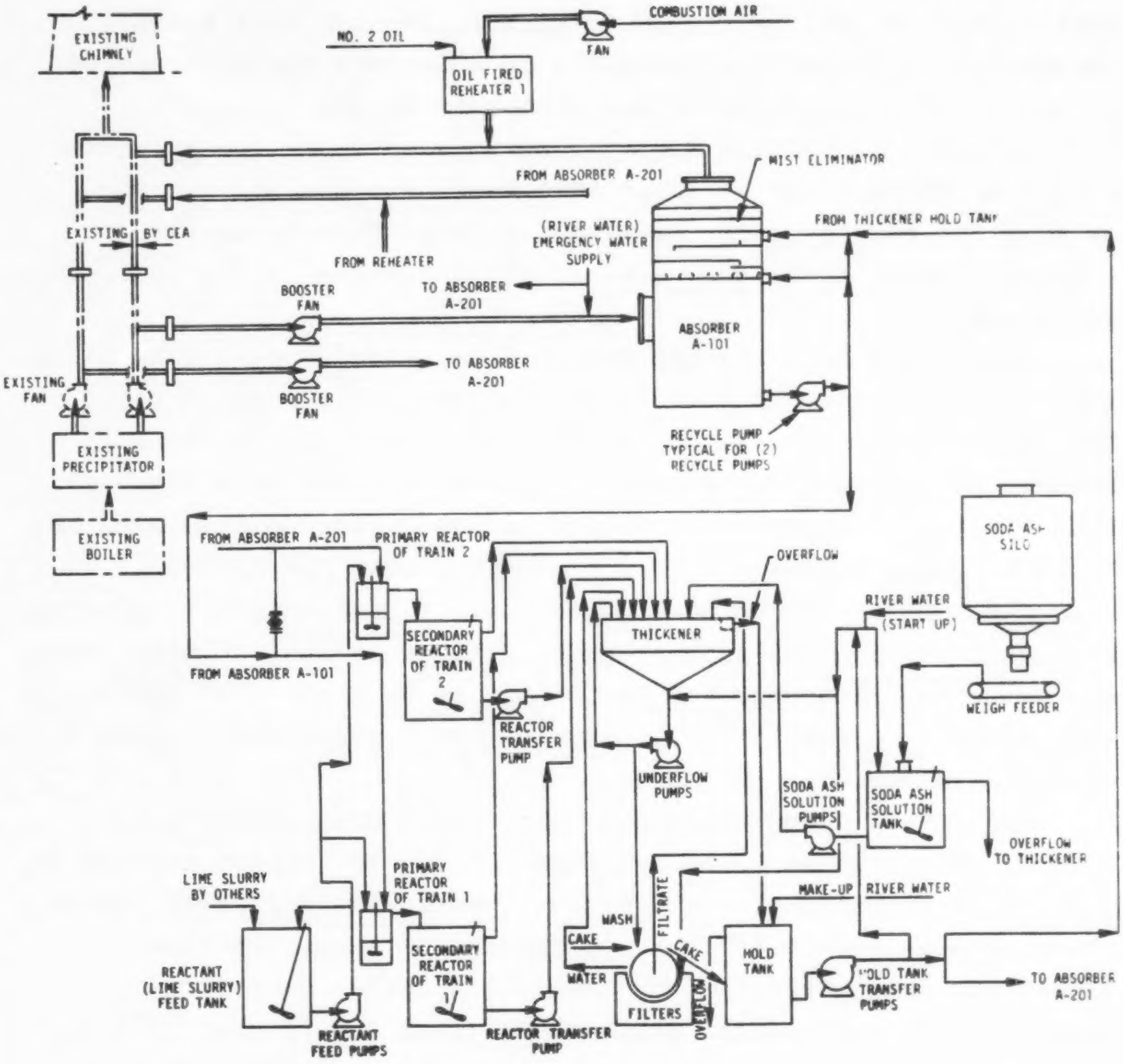
EXISTING CHIMNEY
NO. 2 OIL
OIL FIRED REHEATER 1
FAN
COMBUSTION AIR
FROM ABSORBER A-201
MIST ELIMINATOR
EXISTING
BY CEA
FROM REHEATER
(RIVER WATER) EMERGENCY WATER SUPPLY
FROM THICKENER HOLD TANK
BOOSTER FAN
TO ABSORBER A-201
ABSORBER A-101
TO ABSORBER A-201
EXISTING FAN
BOOSTER FAN
RECYCLE PUMP TYPICAL FOR (2) RECYCLE PUMPS
EXISTING PRECIPITATOR
EXISTING BOILER
FROM ABSORBER A-201
PRIMARY REACTOR OF TRAIN 2
OVERFLOW
SODA ASH SILO
FROM ABSORBER A-101
SECONDARY REACTOR OF TRAIN 2
THICKENER
RIVER WATER (START UP)
WEIGH FEEDER
REACTOR TRANSFER PUMP
UNDERFLOW PUMPS
SODA ASH SOLUTION PUMPS
SODA ASH SOLUTION TANK
OVERFLOW TO THICKENER
LIME SLURRY BY OTHERS
PRIMARY REACTOR OF TRAIN 1
MAKE-UP RIVER WATER
WASH
FILTRATE
CAKE
CAKE
WATER
REACTANT (LIME SLURRY) FEED TANK
SECONDARY REACTOR OF TRAIN 1
FILTERS
OVERFLOW
HOLD TANK
HOLD TANK TRANSFER PUMPS
TO ABSORBER A-201
REACTANT FEED PUMPS
REACTOR TRANSFER PUMP

Figure 8. Simplified process flow diagram of Cane Run 6 FGD system.

system are summarized in Tables 29, 30, and 31, respectively. Additional information regarding this full-scale dual alkali demonstration project is available in a project manual prepared by the project participants and published by EPA.[4]

In addition to Cane Run 6, LG&E is also operating or planning four FGD systems at their Mill Creek station and two FGD systems for two new units planned for their Trimble County station. These facilities are briefly described in the following paragraphs.

Mill Creek is a planned 4-unit, coal-fired, power-generating station with 3 units currently in service. Mill Creek 1 and 2 are existing units rated at 358 MW (gross) and 350 MW (gross), respectively. In accordance with consent decrees with the U.S. EPA, Air Pollution Control District of Jefferson County, and the Kentucky State Division of Air Pollution, LG&E has agreed to retrofit FGD systems on both these units. Contracts were awarded to C-E to provide FGD systems which will use either carbide lime or commercial limestone and be in service by April 1981 and April 1982 for Mill Creek 1 and 2, respectively. These FGD systems are currently under construction.

Mill Creek 3 and 4 are new units which must comply with Federal NSPS. These units are rated at 442 MW (gross) and 495 MW (gross), respectively. Mill Creek 3, which was initially placed in service in August 1978, is equipped with a carbide lime slurry FGD system supplied by AAF. This system contains 4 parallel scrubber modules designed to treat 100 percent of the boiler flue gas resulting from the combustion of the same high sulfur bituminous coal burned at LG&E's other stations. The scrubber module design is similar to Cane Run 4 in that mobile-bed contactors are used as the absorber towers. The system's design sulfur dioxide removal efficiency is 85 percent. The FGD system was initially placed in service with the boiler in August 1978 and was certified commercial in March 1979 following the successful completion of performance testing.

TABLE 29. CANE RUN 6 FGD SYSTEM DESIGN BASIS

Unit rating, MW:	
Gross	300
Net	277
Coal (dry basis):	
Sulfur, percent	5.0
Chloride, percent	0.04
Heat content, J/g (Btu/lb)	25,600 (11,000)
Inlet gas conditions:	
Volume, m^3/s (acfm)	503 (1,065,000)
Weight, Mg/h (lb/h)	1530 (3,372,000)
Temperature, °C (°F)	149 (300)
Sulfur dioxide, ppm	3471
Oxygen, percent	5.7
Particulate, ng/J ($lb/10^6$ Btu)	$\leq$ 43 (0.1)
Outlet gas conditions:	
Sulfur dioxide, ppm	$\leq$ 200
Particulate, ng/J ($lb/10^6$ Btu)	$\leq$ 43 (0.1)
Sulfur dioxide removal efficiency, percent	95

TABLE 30. CANE RUN 6 FGD SYSTEM DESIGN OPERATING PARAMETERS

Normal inlet gas operating temperature, °C (°F)	149 (300)
Maximum inlet gas operating temperature, °C (°F)[a]	316 (600)
Normal inlet gas operating pressure, kPa (in. H_2O)	-0.3 to +0.5 (-1 to +2)
Inlet gas density, kg/m^3 (lb/ft^3)	1.25 (0.078)
System pressure drop, kPa (in. H_2O)	2.4 (9.5)
Absorber flue gas velocity, m/s (ft/s)	2.7 (9.0)
Liquor feed to absorbers, liters/s (gpm)	5.43 (8,600)
L/G ratio, liters/m^3 (gpm)[b]	1.3 (9.9)
Liquor active sodium concentration, M	0.45
Saturated gas flow, m^3/s (acfm)	412 (873,000)
Saturated gas temperature, °C (°F)	52 (126)
Reheated gas flow, m^3/s (acfm)	460 (974,000)
Reheated gas temperature, °C (°F)	80 (176)
Makeup soda ash, kg/min (lb/min)[c]	6.2 (13.7)
Lime consumption, kg/min (lb/min)[d]	209 (460)
Fuel oil consumption, liters/s (gpm)	23 (6)
Water consumption, liter/s (gpm)	20.5 (325)
Waste solids production, kg/m (lb/min)	565 (1,246)

[a] Up to 5 minutes.

[b] At saturated gas conditions.

[c] Makeup for sodium salts lost in filter cake.

[d] CaO available in carbide lime is 92.5 percent.

TABLE 31. CANE RUN 6 FGD SYSTEM GUARANTEES

Sulfur dioxide emission	A sulfur dioxide emission of 200 ppm for coal sulfur less than 5 percent and a system removal efficiency of at least 95 percent for coal sulfur greater than 5 percent.
Particulate emission	No particulate emissions will be added to the flue gas as received from the ESP.
Lime consumption	Lime consumption will not exceed 1.05 moles calcium oxide per moles of sulfur dioxide removed from the flue gas.
Sodium carbonate makeup	Soda ash makeup will not exceed 0.045 moles of sodium carbonate per mole of sulfur dioxide removed from the flue gas at an average coal chloride of 0.06 percent. If the average coal chloride exceeds 0.06 percent, then additional sodium carbonate consumption will be allowed at a rate of 0.5 moles per mole of chloride in the flue gas in excess of 0.06 percent coal chloride.
Power consumption	1.1 percent of unit output at peak load (300 MW).
Waste solids properties	A minimum of 55 percent insoluble solids contained in the filter cake.
System availability	A minimum availability of 90 percent for the demonstration period.

Mill Creek 4 is presently under construction and is scheduled for operation in July 1981. This unit is similar to Mill Creek 3 in that it is approximately the same capacity, will burn the same coal, and will use the same emission control stragegy for particulate (ESP's) and sulfur dioxide (carbide lime FGD system supplied by AAF).

LG&E is currently planning a new, coal-fired, power-generating facility located in Bedford, Kentucky. This new station, known as Trimble County, will consist of 4 coal-fired units each nominally rated at 575 MW. Startup dates for these units are currently scheduled for July 1984, July 1986, 1988, and 1990, for Trimble County 1, 2, 3, and 4, respectively. With respect to Trimble County 1 and 2, LG&E currently plans to fire high sulfur bituminous coal and control emissions with ESP's and FGD systems. The FGD systems currently being considered are wet scrubbers which will remove 90 percent of the inlet sulfur dioxide and produce a nonrecoverable waste material. Neither a process nor a system supplier have yet been selected for these FGD systems.

SECTION 5

FGD ECONOMICS

INTRODUCTION

In an effort to improve the comparability of the capital and annual costs associated with utility FGD systems, PEDCo Environmental has been conducting an on-going program for the U.S. EPA which involves the acquisition of reported capital and annual costs for the operational FGD systems and then adjusting this data to a common basis. The intent of performing such a program stems from the difficulty of comparing the costs that are reported by the owning/operating utilities. Many of the capital and operating costs reported for the operational FGD systems are site-sensitive and involve different FGD battery limits and expenditures made in different years. To accommodate these differences, the cost data for the systems were analyzed and adjusted to produce accurate and comparable data for the sulfur dioxide portion of the emission control system.

APPROACH

The sole intent of the adjusting procedure was to establish accurate costs of FGD systems on a common basis, not to critique the design or reasonableness of the costs reported by the utility. Adjustments focused primarily on the following items:

- Capital costs were adjusted to July 1, 1977, dollars using the Chemical Engineering Index. Capital costs, represented in dollars/kilowatt ($/kW), were expressed in terms of gross megawatts (MW).

- Gross unit capacity was used to express all FGD capital expenditures because the capital requirements of an FGD system depends on actual boiler size before derating for auxiliary and air quality control power requirements.

- Particulate control costs were deducted in an effort to estimate the incremental cost of sulfur dioxide control.

- Capital costs associated with the modification or installation of equipment that is not part of the FGD system but is needed for its proper functioning were included (e.g., stack lining, modification to existing ductwork or fans).

- Indirect charges were adjusted to provide adequate funds for engineering, field expenses, legal expenses, insurance, interest during construction, allowance for startup, taxes, and contingencies.

- Annual costs, represented in mills/kilowatt-hour (mills/kWh), were expressed in terms of net megawatts (MW).

- Net unit capacity was used to express all FGD annual expenditures because the annual cost requirement of an FGD system depends on the actual amount of kilowatt-hours (kWh) produced by the unit after derating for auxiliary and air quality control power requirements.

- Annual costs were adjusted to a common capacity factor (65 percent).

- Replacement power costs were not included.

- Sludge disposal costs were adjusted to reflect the costs of sulfur dioxide waste disposal only (i.e., excluding fly ash disposal).

- A 30-year life was assumed for all process and economic considerations for new units. A 20-year life was assumed for retrofit units.

DESCRIPTION OF COST ELEMENTS

Capital costs consist of direct, indirect, contingency, and other capital costs. Direct costs include the "bought-out" cost of the equipment, installation, and site development. Indirect costs include interest during construction, contractor's fees and expenses, engineering, legal expenses, taxes, insurance, allowance for startup and shakedown, and spares. Contingency costs include those resulting from malfunctions, equipment alterations, and similar unforeseen sources. Other capital costs include the nondepreciable items of land and working capital.

Annual costs consist of direct, fixed, and overhead costs. Direct costs include the cost of raw materials, utilities, operating labor and supervision, and maintenance and repair. Fixed costs include depreciation, interim replacement, insurance, taxes, and interest on borrowed capital. Overhead costs include those of plant and payroll expenses.

RESULTS

The reported and adjusted capital and annual costs associated with the Cane Run 4 and 5 FGD systems are presented in Appendices D and E of this report. The estimated capital and annual costs associated with the Cane Run 6 FGD system were prepared and published in the demonstration project manual.[5] The results of this cost analysis for the Cane Run FGD systems are summarized in the following paragraphs.

Reported and Adjusted Capital and Annual Costs

The reported and adjusted capital and annual costs provided by LG&E for Cane Run 4 and 5 are summarized in Tables 32 and 33. The total capital costs reported by LG&E were $12,467,000 for Cane Run 4 and $12,481,000 for Cane Run 5. Based on gross unit capacity, these costs are equivalent to $66.6/kW and $62.2/kW, respectively. The total annual cost reported by the utility for Cane Run 4 was an estimate of 2.5 to 3.0 mills/kWh (net). No annual costs were reported for Cane Run 5 at the time of data collection because of the FGD system's recent operating status.

TABLE 32. CANE RUN 4 AND 5 REPORTED AND ADJUSTED CAPITAL COSTS

Adjustments	Costs, 10^6 \$ (\$/gross kW)	
	Cane Run 4	Cane Run 5
Total reported capital cost	12.647 (66.5)	12.481 (62.4)
Additional waste disposal capacity adjustment	0.900	0.900
Conversion to July 1, 1977, dollars	1.774	0.125
Total adjusted capital cost	15.321 (80.6)	13.506 (67.5)

TABLE 33. CANE RUN 4 AND 5 ADJUSTED ANNUAL COSTS

Category	Costs, 10^6 \$ (mills/net kWh)	
	Cane Run 4	Cane Run 5
Variable charges	3.355 (3.24)	3.287 (3.01)
Overhead	0.403 (0.39)	0.503 (0.46)
Fixed charges	2.234 (2.15)	2.276 (2.09)
Total annual	5.992 (5.78)	6.066 (5.56)

The adjusted capital and annual costs calculated for Cane Run 4 and 5 were $15,321,000 or $80.6/kW (gross) and $5,992,000 or 5.8 mills/kWh (net) for Cane Run 4; and $13,506,000 or $67.5/kW (gross) and $6,087,000 or 5.6 mills/kWh (net) for Cane Run 5.

With respect to Cane Run 6, the estimated capital and annual costs published in the project manual for the dual alkali demonstration system are summarized in Tables 34 and 35. These costs are already adjusted in that all the elements required for determining the total capital and annual costs are included. Further, these values are represented in common dollars. The capital investment of $17,379,000 are roughly equivalent to September 1977 dollars. The annual cost of $5,101,400 represents an estimate for operations during 1979. These costs are equivalent to 57.9/kW (gross) and 3.24 mills/kWh (net). These costs compare favorably well with those reported by LG&E for Cane Run 4 and 5.

TABLE 34. ESTIMATED CAPITAL COSTS FOR CANE RUN 6 FGD SYSTEM

Cateogry	Cost, $ ($/gross kW)
Materials:	
Major equipment cost	7,037,000
Other materials cost	2,525,000
Sludge disposal equipment	900,000
Additive slurry system	700,000
Total materials cost	11,162,000
Erection:	
Direct labor	3,034,000
Field supervision	273,000
Total erection cost	3,307,000
Engineering:	
System supplier engineering	1,323,000
LG&E engineering	303,000
Consulting engineering	852,000
Total engineering cost	2,478,000
Spare parts	232,000
Working capital	200,000
Total capital	17,379,000 (57.9)

TABLE 35. ESTIMATED ANNUAL COSTS FOR CANE RUN 6 FGD SYSTEM[a]

Category	Cost, $ (mills/net kWh)
Direct costs:	
Carbide lime	780,500
Soda ash	150,400
Fuel oil	775,200
Electricity	161,900
Water	6,300
Sludge Removal	372,400
Maintenance materials	279,000
Labor	
Operation	215,000
Maintenance	217,600
Analysis	20,800
Supervision	40,000
Total direct costs	3,019,000
Indirect costs:	
Overhead	293,000
Interest	1,064,500
Depreciation	724,700
Total indirect costs	2,082,300
Total annual costs	5,101,400 (3.24)

[a] Based on the unit's gross peak generating capacity of 300 MW and a capacity factor of 60 percent.

REFERENCES

1. Holcombe, L.J., and K.W. Luke. Characterization of Carbide Lime to Identify Sulfite Oxidation Inhibitors. Prepared for the U.S. Environmental Agency under Contract No. 68-02-2608, Task No. 21. EPA-600/7-78-176, September 1978.

2. Kelly, W.E., and C. Sedman. Air Pollution Emission Test, Volume I: First Interim Report - Continuous Sulfur Dioxide Monitoring at Steam Generators. Prepared by the U.S. Environmental Protection Agency under Contract No. 68-02-2818, Work Assignment 2. EMB Report No. 77SPP23A, August 1978.

3. Kelly, W.E., and C. Sedman. Air Pollution Emission Test, Volume II: Data Listings, Averages and Statistical Summaries - Continuous Sulfur Dioxide Monitoring at Steam Generators. Prepared by the U.S. Environmental Protection Agency under Contract No. 68-02-2818, Work Assignment 2. EMB Report No. 77SPP23A, August 1978.

4. VanNess, R.P., et al. Project Manual for Full-Scale Dual Alkali Demonstration at Louisville Gas and Electric Co. - Preliminary Design and Cost Estimate. Prepared for the U.S. Environmental Protection Agency under Contract No. 68-02-2189. EPA-600/7-78-010, January 1978.

5. Ibid.

APPENDIX A

PLANT SURVEY FORM

A. Company and Plant Information

1. Company name: Louisville Gas and Electric (LG&E)
2. Main office: 311 West Chestnut Street
3. Plant name: Cane Run
4. Plant location: Lousiville, Kentucky
5. Responsible officer: R.L. Royer
6. Plant manager: S.J. Lindauer
7. Plant contact: Robert Van Ness
8. Position: Manager, Environmental Affairs
9. Telephone number: (502) 566-4216
10. Date information gathered: 2/22/78 and 9/11/79

Participants in meeting	Affiliation
R. Van Ness	LG&E
B. Statnick	U.S. EPA
M. Maxwell	U.S. EPA
B. Laseke	PEDCo Environmental
M. Smith	PEDCo Environmental
M. Melia	PEDCo Environmental
N. Kaplan	U.S. EPA

B. Plant and Site Data

1. UTM coordinates:

2. Sea Level elevation:

3. Plant site plot plan (Yes, No):
(include drawing or aerial overviews)

4. FGD system plan (Yes, No):

5. General description of plant environs: Situated along the Ohio River in a moderately industrialized area

6. Coal shipment mode(s): Barge and truck

C. FGD Vendor/Designer Background

1. Process: Carbide lime slurry

2. Developer/licensor: American Air Filter Co.

3. Address: 215 Central Avenue
Louisville, Kentucky 40201

4. Company offering process:

Company: Amercian Air Filter Co.

Address: 215 Central Avenue

Location: Louisville, Kentucky 40201

Company contact: J. Onnen

Position: SO_2 Product Manager

Telephone number: 502/588-9125

5. Architectural/engineer:

Company: Fluor-Pioneer

Address: 200 West Monroe

Location: Chicago, Illinois 60606

Company contact:

Position:

Telephone number: (312)/368-3700

D. Boiler Data

1. Boiler: Cane Run 4
2. Boiler manufacturer: Combustion Engineering
3. Boiler service (base, intermediate, cycling, peak): Base Load
4. Year placed in service: 1962
5. Total hours operation (date)::
6. Remaining life of unit: 18 yr.
7. Boiler type: Pulverized coal
8. Served by stack no.: 4
9. Stack height: 76.2 m (250 ft)
10. Stack top inner diameter:
11. Unit ratings (MW):

Gross unit rating: 190

Net unit rating without FGD: 185

Net unit rating with FGD: 182

Name plate rating:

12. Unit heat rate:

Heat rate without FGD:

Heat rate with FGD: 10, 740, kJ/net kWh (10, 180 Btu/net kWh)

13. Boiler capacity factor, (1977): 55

14. Fuel type: Coal

15. Flue gas flow rate:

Maximum: 346 m^3/s (734,000 acfm)

Temperature: 163°C (325°F)

16. Total excess air:

17. Boiler efficiency:

E. Coal Data

1. Coal supplier(s):

Name(s): Peabody Coal Company

Location(s): Star Mine

Mine location(s): Western Kentucky

County, State:

Seam:

2. Gross heating value: 27,700 J/g (11,500 Btu/lb) (maximum)

3. Ash (maximum): 14.0%

4. Moisture: 12.0% (maximum)

5. Sulfur (maximum): 4.0%

6. Chloride: 0.07% (maximum)

7. Ash composition (See Table A1)

Table A1

Constituent	Percent weight
Silica, SiO_2	
Alumina, Al_2O_3	
Titania, TiO_2	
Ferric oxide, Fe_2O_3	
Calcium oxide, CaO	
Magnesium oxide, MgO	Not available
Sodium oxide, Na_2O	
Potassium oxide, K_2O	
Phosphorous pentoxide, P_2O_5	
Sulfur trioxide, SO_3	
Other	
Undetermined	

F. Atmospheric Emission Regulations

1. Applicable particulate emission regulation

a) Current requirement: 43 ng/J (0.1 lb/MM Btu)

Regulation and section: ______

b) Future requirement: ______

Regulation and section: ______

2. Applicable SO_2 emission regulation

a) Current requirement: 516 ng/J (1.2 lb/MM Btu)

Regulation and section No.: Jefferson County KRS Chapter 77 and KRS Chapter 224

b) Future requirement: ______

Regulation and section: ______

G. Chemical Additives: (Includes all reagent additives - absorbents, precipitants, flocculants, coagulants, pH adjusters, fixatives, catalysts, etc.)

1. Trade name: Carbide lime
Principal ingredient: $Ca(OH)_2$ 92.5%
Function: SO_2 Absorbent
Source/manufacturer: Airco, Inc.
Quantity employed: 107 Gg (118,000 ton/yr) (estimate)*
Point of addition: Recycle tank

2. Trade name: Bety Polyfloc 1100
Principal ingredient:
Function: Flocculant
Source/manufacturer: Betz
Quantity employed: 0.5% solution (continuous feed)
Point of addition: Thickener

3. Trade name: Not applicable (N/A)
Principal ingredient:
Function:
Source/manufacturer:
Quantity employed:
Point of addition:

4. Trade name: N/A
Principal ingredient:
Function:
Source/manufacturer:
Quantity employed:
Point of addition:

* PEDCo Environmental estimate

5. Trade name: N/A

Principal ingredient:

Function:

Source/manufacturer:

Quantity employed:

Point of addition:

H. Equipment Specifications

1. Electrostatic precipitator(s)

Number: Two (2)

Manufacturer:

Design removal efficiency: 99%

Outlet temperature: 163°C (325°F)

Pressure drop:

2. Mechanical collector(s) N/A

Number:

Type:

Size:

Manufacturer:

Design removal efficiency:

Pressure drop:

3. Particulate scrubber(s) N/A (Quencher and flooded elbow)*

Number: Two (2)

Type: Wetted-wall conical frustum section (quench)

Manufacturer: American Air Filter (AAF)

Dimensions:

Material, shell: Carbon steel

---

*Absorber preceded by quencher and flooded elbow

Material, shell lining:

Material, internals:

No. of modules per train: One (1)

No. of stages per module: Two (2) (quench and flooded elbow)

No. of nozzles or sprays: Tangential and cocurrent

Nozzle type: Injector's nozzles

Nozzle size:

Boiler load capacity: 50% (each module)

Gas flow and temperature: 173 m^3/s (367,000 acfm) 163°C (325°F)

Liquid recirculation rate: 112 liter/s (1760 gpm)

Modulation:

L/G ratio: 0.6 liter/m^3 (4.8 gal/10^3 acf)

Pressure drop: 1.25 kPa (5.0 in H_2O)

Modulation:

Superficial gas velocity:

Particulate removal efficiency (design/actual):

Inlet loading:

Outlet loading:

SO_2 removal efficiency (design/actual):

Inlet concentration:

Outlet concentration:

4. SO_2 absorber(s)

Number: Two (2)

Type: Mobile bed contactor

Manufacturer: AAF

Dimensions: 6.1 m x 6.1 m x 8.4 m (20 ft x 20 ft x 27.5 ft)

Material, shell: Carbon steel

Material, shell lining: Precrete and Plasite 4005

Material, internals: Polyurethane balls, ceramic nozzles

No. of modules per train: One (1)

No. of stages per module: One (1)

Packing/tray type: 3.2-cm (1.25-in.) diameter polyurethane balls

Packing/tray dimensions:

No. of nozzles or sprays:

Nozzle type:

Nozzle size:

Boiler load capacity: 50%

Gas flow and temperature: 138 m^3/s (291,500 acfm) 53°C (127°F)

Liquid recirculation rate: 1000 liter/s (15,865 gpm)

Modulation:

L/G ratio: 8 l/m^3 (60.0 gal/1000 acf)

Pressure drop: 1.0 kPa (4.0 in. H_2O)

Modulation:

Superficial gas velocity: 3 to 4 m/s (10 to 13 ft/s)

Particulate removal efficiency (design/actual):

Inlet loading:

Outlet loading:

SO_2 removal efficiency (design/actual): 85 %/86-89%*

Inlet concentration: 2800 ng/J (6.5 lb/10^6 Btu)+

Outlet concentration: 344 ng/J (0.8 lb/10^6 Btu)*

5. Wash water tray(s) N/A

Number:

* Results of acceptance test.

+ Estimate.

Type: ______

Materials of construction: ______

Liquid recirculation rate: ______

Source of water: ______

6. Mist eliminator(s)

Number: Two (2)

Type: Chevron

Materials of construction: SS and Plasite 4005 (duct area)

Manufacturer: ______

Configuration (horizontal/vertical): Horizontal

Number of stages: 2

Number of passes per stage: 3

Mist eliminator depth: ______

Vane spacing: 2.5 - 3.8 cm (1 - 1.5 in.)

Vane angles: ______

Type and location of wash system: Fresh water over and undersprays

Superficial gas velocity: 3.1 m/s (10 fps)

Freeboard distance: 1.8 m (6 ft.)

Pressure drop: 1.2 - 3.0 kPa (0.5 - 1.2 in. H_2O)

Comments: Intermittent wash sprayed 2 min. every 5 min. at 2.5 liter/s (40 gpm) and 483 kPa (70 psig)

7. Reheater(s): Two (2)

Type (check appropriate category): ______

☐ in-line

☐ indirect hot air

☒ direct combustion

☐ bypass

☐ exit gas recirculation

☐ waste heat recovery

☐ other

Gas conditions for reheat:

Flow rate: 275 m^3/s (583,000 acfm)

Temperature: 53°C (127°F)

SO_2 concentration: 350 ppm (dry) (approximate)

Heating medium: Combustion gases

Combustion fuel: No. 2 fuel oil

Percent of gas bypassed for reheat: None

Temperature boost (ΔT): 28°C (50°F)

Energy required:

Comments: Reheat burners added to discharge ducts during initial operations; originally, no reheat was included in system (wet stack).

8. Fan(s)

Number: Two (2)

Type: Forced-draft booster fan

Materials of construction: Carbon steel

Manufacturer: Buffalo Forge/American Standard fluid drives

Location: Between ESP and FGD system

Rating: 930 kW (1250 hp) and 720 rpm

Pressure drop:

9. Recirculation tank(s):

Number: Two (2)

Materials of construction: Reinforced concrete

Function: Slurry recirculation, reaction, and bleed

Configuration/dimensions: Rectangular, 3 compartments

Capacity: 1,703,000 liters (450,000 gal)

Retention time: 25 minutes (8 min/compartment)

Covered (yes/no): No.

Agitator: Six (6) - 1/compartment

10. Recirculation/slurry pump(s):

Number: Six (6)

Type: Recirculation (quencher, absorber)

Manufacturer: Denver

Materials of construction: Rubber-lined

Head: 30 m (100 ft)

Capacity: 371 l/s (5875 gpm)

11. Thickener(s)/clarifier(s)

Number: One (1)

Type: Type B

Manufacturer: Eimco

Materials of construction: Rubber-lined carbon steel*

Configuration: Circular

Diameter: 26 m (85 ft)

Depth: 4.2 m (14 ft)

Rake speed:

Retention time:

12. Vacuum filter(s) N/A

* All submerged parts are rubber covered.

Number: ______________________________

Type: ______________________________

Manufacturer: ______________________________

Materials of construction: ______________________________

Belt cloth material: ______________________________

Design capacity: ______________________________

Filter area: ______________________________

13. Centrifuge(s) N/A

Number: ______________________________

Type: ______________________________

Manufacturer: ______________________________

Materials of construction: ______________________________

Size/dimensions: ______________________________

Capacity: ______________________________

14. Interim sludge pond(s) N/A

Number: ______________________________

Description: ______________________________

Area: ______________________________

Depth: ______________________________

Liner type: ______________________________

Location: ______________________________

Service Life: ______________________________

Typical operating schedule: ______________________________

____

Ground water/surface water monitors: ______________________________

____

15. Final disposal site(s)

Number: One (1)

Description: Lined pond

Area:

Depth:

Location: On-site

Transportation mode: Pipeline

Service life:

Typical operating schedule: Continuous: 68 kg/h (151 lb/h) of dry sludge produced per 0.9 Mg (ton) of coal burned (design)

16. Raw materials production N/A

Number:

Type:

Manufacturer:

Capacity:

Product characteristics:

I. Equipment Operation, Maintenance, and Overhaul Schedule

1. Scrubber(s)

Design life:

Elapsed operation time:

Cleanout method:

Cleanout frequency:

Cleanout duration:

Other preventive maintenance procedures:

2. Absorber(s)

Design life: ______________________________

Elapsed operation time: ______________________

Cleanout method: ___________________________

Cleanout frequency: _________________________

Cleanout duration: __________________________

Other preventive maintenance procedures: __________

____

3. Reheater(s)

Design life: ______________________________

Elapsed operation time: ______________________

Cleanout method: ___________________________

Cleanout frequency: _________________________

Cleanout duration: __________________________

Other preventive maintenance procedures: __________

____

4. Fan(s)

Design life: ______________________________

Elapsed operation time: ______________________

Cleanout method: ___________________________

Cleanout frequency: _________________________

Cleanout duration: __________________________

Other preventive maintenance procedures: __________

____

5. Mist eliminator(s)

Design life: ______________________________

Elapsed operation time: ______________________

Cleanout method: Wash water sprays

Cleanout frequency: 2 min. every 5 min.

Cleanout duration: ________

Other preventive maintenance procedures: ________

6. Pump(s)

Design life: ________

Elapsed operation time: ________

Cleanout method: ________

Cleanout frequency: ________

Cleanout duration: ________

Other preventive maintenance procedures: ________

7. Vacuum filter(s)/centrifuge(s) N/A

Design life: ________

Elapsed operation time: ________

Cleanout method: ________

Cleanout frequency: ________

Cleanout duration: ________

Other preventive maintenance procedures: ________

8. Sludge disposal pond(s)

Design life: ________

Elapsed operation time: ________

Capacity consumed: ________

Remaining capacity: ________

Cleanout procedures: ________________________________

____

J. Instrumentation See text of report (Section 3, Process Control)

A brief description of the control mechanism or method of measurement for each of the following process parameters:

- Reagent addition: ________________________________

  ____
- Liquor solids content: ________________________________

  ____
- Liquor dissolved solids content: ________________________________

  ____
- Liquor ion concentrations

  Chloride: ________________________________

  ____

  Calcium: ________________________________

  ____

  Magnesium: ________________________________

  ____

  Sodium: ________________________________

  ____

  Sulfite: ________________________________

  ____

  Sulfate: ________________________________

  ____

  Carbonate: ________________________________

  ____

  Other (specify): ________________________________

  ____

- Liquor alkalinity: ______________________

- Liquor pH: ______________________

- Liquor flow: ______________________

- Pollutant (SO_2, particulate, NO_x) concentration in flue gas: ______________________

- Gas flow: ______________________

- Waste water ______________________

- Waste solids: ______________________

Provide a diagram or drawing of the scrubber/absorber train that illustrates the function and location of the components of the scrubber/absorber control system.

Remarks: ______________________

K. Discussion of Major Problem Areas:

1. Corrosion: ______________________

2. Erosion:

3. Scaling:

4. Plugging:

5. Design problems:

6. Waste water/solids disposal:

____

7. Mechanical problems: __________________________

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L. General comments: ______________________________

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APPENDIX B

PLANT SURVEY FORM

A. Company and Plant Information

1. Company name: Louisville Gas and Electric (LG&E)
2. Main office: 311 West Chestnut Street
3. Plant name: Cane Run
4. Plant location: Lousiville, Kentucky
5. Responsible officer: R.L. Royer
6. Plant manager: S.J. Lindauer
7. Plant contact: Robert Van Ness
8. Position: Manager, Environmental Affairs
9. Telephone number: (502) 566-4216
10. Date information gathered: 2/22/78 and 9/11/79

Participants in meeting	Affiliation
R. Van Ness	LG&E
B. Statnick	U.S. EPA
M. Maxwell	U.S. EPA
B. Laseke	PEDCo Environmental
M. Smith	PEDCo Environmental
M. Melia	PEDCo Environmental
N. Kaplan	U.S. EPA

B. Plant and Site Data

1. UTM coordinates:

2. Sea Level elevation:

3. Plant site plot plan (Yes, No):
(include drawing or aerial overviews)

4. FGD system plan (Yes, No): Yes

5. General description of plant environs: Situated along the Ohio River in a moderately industralized area

6. Coal shipment mode(s): Barge and truck

C. FGD Vendor/Designer Background

1. Process: Carbide lime slurry

2. Developer/licensor: Combustion Engineering

3. Address: 1000 Prospect Hill Road
Windsor, Conn. 06095

4. Company offering process:

Company: Combustion Engineering

Address: 1000 Prospect Hill Road

Location: Windsor, Conn. 06095

Company contact: A.J. Snider

Position: Manager, Environmental Control

Telephone number: (203)/688-1911

5. Architectural/engineer:

Company: Fluor-Pioneer

Address: 200 West Monroe

Location: Chicago, Illinois 60606

Company contact:

Position:

Telephone number: (312)/368-3700

D. Boiler Data

1. Boiler: Cane Run 5

2. Boiler manufacturer: Riley Stoker

3. Boiler service (base, intermediate, cycling, peak):

Base load

4. Year placed in service: 1966

5. Total hours operation (date)::

6. Remaining life of unit:

7. Boiler type: Pulverized coal

8. Served by stack no.: 5

9. Stack height: 76 m (250 ft)

10. Stack top inner diameter:

11. Unit ratings (MW):

Gross unit rating: 200

Net unit rating without FGD: 195

Net unit rating with FGD: 192

Name plate rating:

12. Unit heat rate:

Heat rate without FGD:

Heat rate with FGD: 10,529 J/net kWh (9,980 Btu/net kWh)

13. Boiler capacity factor, (1977): 60%

14. Fuel type: Coal

15. Flue gas flow rate:

Maximum: 307 m^3/s (650,000 acfm)

Temperature: 163°C (325°F)

16. Total excess air:

17. Boiler efficiency:

E. Coal Data

1. Coal supplier(s):

Name(s): Peabody Coal Company

Location(s): Star Mine

Mine location(s): Western Kentucky

County, State:

Seam:

2. Gross heating value: 27,700 J/g (11,500 Btu/lb) (maximum)

3. Ash (maximum): 14.0%

4. Moisture: 12.0% (maximum)

5. Sulfur (maximum): 4.0%

6. Chloride: 0.07% (maximum)

7. Ash composition (See Table A1)

Table A1

Constituent	Percent weight
Silica, SiO_2	
Alumina, Al_2O_3	
Titania, TiO_2	
Ferric oxide, Fe_2O_3	
Calcium oxide, CaO	
Magnesium oxide, MgO	Not available
Sodium oxide, Na_2O	
Potassium oxide, K_2O	
Phosphorous pentoxide, P_2O_5	
Sulfur trioxide, SO_3	
Other	
Undetermined	

F. Atmospheric Emission Regulations

1. Applicable particulate emission regulation

   a) Current requirement: 43 ng/J (0.1 lb/MM Btu)

   Regulation and section: ______

   b) Future requirement: ______

   Regulation and section: ______

2. Applicable SO_2 emission regulation

   a) Current requirement: 516 ng/J (1.2 lb/MM Btu)

   Regulation and section No.: Jefferson County KRS Chapter 77 and KRS Chapter 224

   b) Future requirement: ______

   Regulation and section: ______

G. Chemical Additives: (Includes all reagent additives - absorbents, precipitants, flocculants, coagulants, pH adjusters, fixatives, catalysts, etc.)

1. Trade name: Carbide lime
   Principal ingredient: $Ca(OH)_2$ (92.5%)
   Function: SO_2 Absorbent
   Source/manufacturer: Airco, Inc.
   Quantity employed: 124 Gg (137,000 ton/yr) (estimate)
   Point of addition: Recycle tank
2. Trade name: Betz Polyfloc 1100
   Principal ingredient:
   Function: Flocculant
   Source/manufacturer: Betz
   Quantity employed: 0.5% solution (continuous feed)
   Point of addition: Thickener
3. Trade name: Not applicable (N/A)
   Principal ingredient:
   Function:
   Source/manufacturer:
   Quantity employed:
   Point of addition:
4. Trade name: N/A
   Principal ingredient:
   Function:
   Source/manufacturer:
   Quantity employed:
   Point of addition:

---

* PEDCo Environmental estimate.

5. Trade name: N/A

Principal ingredient:

Function:

Source/manufacturer:

Quantity employed:

Point of addition:

H. Equipment Specifications

1. Electrostatic precipitator(s)

Number: Two (2)

Manufacturer:

Design removal efficiency: 99.0%

Outlet temperature: 163°C (325°F)

Pressure drop:

2. Mechanical collector(s) N/A

Number:

Type:

Size:

Manufacturer:

Design removal efficiency:

Pressure drop:

3. Particulate scrubber(s) N/A*

Number:

Type:

Manufacturer:

Dimensions:

Material, shell:

* Secondary particulate control provided by the spray tower absorbers.

Material, shell lining:

Material, internals:

No. of modules per train:

No. of stages per module:

No. of nozzles or sprays:

Nozzle type:

Nozzle size:

Boiler load capacity:

Gas flow and temperature:

Liquid recirculation rate:

Modulation:

L/G ratio:

Pressure drop:

Modulation:

Superficial gas velocity:

Particulate removal efficiency (design/actual):

Inlet loading:

Outlet loading:

SO_2 removal efficiency (design/actual):

Inlet concentration:

Outlet concentration:

4. SO_2 absorber(s)

Number: Two (2)

Type: Spray tower

Manufacturer: Combustion Engineering

Dimensions: 8 m x 9.5 m (26 ft x 31 ft)

Material, shell: Carbon steel

Material, shell lining: Precrete

Material, internals: Ceramic nozzles

No. of modules per train: One (1)

No. of stages per module: One (1)

Packing/tray type: None

Packing/tray dimensions: N/A

No. of nozzles or sprays: 84

Nozzle type: Ceramic

Nozzle size: ______

Boiler load capacity: 50% (per module)

Gas flow and temperature: 154 m^3/s @ 163°C (325,000 acfm @ 325°F)

Liquid recirculation rate: 1135 liters/s (17,500 gpm)

Modulation: ______

L/G ratio: 7.4 liters/m^3 (55 gal/10^3 acf)

Pressure drop: 0.5 kPa (2.0 in. H_2O)

Modulation: ______

Superficial gas velocity: 2.1 m/s (7.0 ft/s)

Particulate removal efficiency (~~design~~/actual): 50-88*

Inlet loading: 39-143 ng/J (0.089-0.333 lb/10^6 Btu)*

Outlet loading: 15-26 ng/J (0.035- 0.061 lb/10^6 Btu)*

SO_2 removal efficiency (design/actual): 85.0%/91.0

Inlet concentration: 2481-2778 ng/J (5.77-6.46 lb/10^6 Btu)*

Outlet concentration: 211-249 ng/J (0.49-0.58 lb/10^6 Btu)*

5. Wash water tray(s) N/A

Number: ______

* Results of acceptance test.

Type: ________

Materials of construction: ________

Liquid recirculation rate: ________

Source of water: ________

6. Mist eliminator(s)

Number: Two (2)

Type: Chevron, A-frame

Materials of construction: FRP

Manufacturer: ________

Configuration (horizontal/vertical): Horizontal

Number of stages: 3

Number of passes per stage: 2

Mist eliminator depth: ________

Vane spacing: ________

Vane angles: ________

Type and location of wash system: Blended water overspray and underspray

Superficial gas velocity: 2.1 m/s (7.0 ft/s)

Freeboard distance: ________

Pressure drop: 0.12 kPa (0.5 in. H_2O)

Comments: Intermittent wash frequency (once/24 h). 3 stages includes 2 stages of chevrons preceded by a precollector (bulk entrainment separator)

7. Reheater(s): Two (2)

Type (check appropriate category): ________

☒ in-line

☐ indirect hot air

☐ direct combustion

☐ bypass

☐ exit gas recirculation

☐ waste heat recovery

☐ other

Gas conditions for reheat:

Flow rate: 265 m^3/s (562,000 acfm)

Temperature: 53°C (126°F)

SO_2 concentration: 250-300 ppm SO_2

Heating medium: Steam

Combustion fuel: N/A

Percent of gas bypassed for reheat: None

Temperature boost (ΔT): 22°C (40°F)

Energy required:

Comments: Reheater tubes are circumferential finned tubes constructed of carbon steel and arranged vertically in horizontal discharge ducts atop absorbers

8. Fan(s)

Number: Two (2)

Type: Induced-draft booster fan

Materials of construction: Carbon steel

Manufacturer:

Location: Between reheaters and stack

Rating:

Pressure drop:

9. Recirculation tank(s):

Number: One

Materials of construction: Carbon steel

Function: Slurry recycle

Configuration/dimensions: Rectangular

Capacity: 1,779,000 liters (470,000 gal)

Retention time: 10 min

Covered (yes/no): No

Agitator: Two (2)

10. Recirculation/slurry pump(s):

Number: Two (2) [One per module]

Type: Centrifugal

Manufacturer:

Materials of construction: Rubber-lined

Head:

Capacity: 1140 l/s (18,000 gpm)

11. Thickener(s)/clarifier(s)

Number: One (1)

Type:

Manufacturer:

Materials of construction: Rubber-lined carbon steel

Configuration: Circular

Diameter: 33.5m (110 ft)

Depth:

Rake speed:

Retention time:

12. Vacuum filter(s) N/A

Number: ____________________

Type: ____________________

Manufacturer: ____________________

Materials of construction: ____________________

Belt cloth material: ____________________

Design capacity: ____________________

Filter area: ____________________

13. Centrifuge(s) N/A

Number: ____________________

Type: ____________________

Manufacturer: ____________________

Materials of construction: ____________________

Size/dimensions: ____________________

Capacity: ____________________

14. Interim sludge pond(s) N/A

Number: ____________________

Description: ____________________

Area: ____________________

Depth: ____________________

Liner type: ____________________

Location: ____________________

Service Life: ____________________

Typical operating schedule: ____________________

____

Ground water/surface water monitors: ____________________

____

15. Final disposal site(s)

Number: One (1)

Description: Lined pond

Area:

Depth:

Location: On-site

Transportation mode: Pipeline

Service life:

Typical operating schedule: Continuous: 163 kg (360 lb) of dry sludge produced per 0.9 Mg (ton) of coal burned

16. Raw materials production N/A

Number:

Type:

Manufacturer:

Capacity:

Product characteristics:

I. Equipment Operation, Maintenance, and Overhaul Schedule

1. Scrubber(s)

Design life:

Elapsed operation time:

Cleanout method:

Cleanout frequency:

Cleanout duration:

Other preventive maintenance procedures:

2. Absorber(s)

Design life: ______________________________

Elapsed operation time: ______________________

Cleanout method: ___________________________

Cleanout frequency: _________________________

Cleanout duration: __________________________

Other preventive maintenance procedures: ____________

____

3. Reheater(s)

Design life: ______________________________

Elapsed operation time: ______________________

Cleanout method: ___________________________

Cleanout frequency: _________________________

Cleanout duration: __________________________

Other preventive maintenance procedures: ____________

____

4. Fan(s)

Design life: ______________________________

Elapsed operation time: ______________________

Cleanout method: ___________________________

Cleanout frequency: _________________________

Cleanout duration: __________________________

Other preventive maintenance procedures: ____________

____

5. Mist eliminator(s)

Design life: ______________________________

Elapsed operation time: ______________________

Cleanout method: ____________________

Cleanout frequency: ____________________

Cleanout duration: ____________________

Other preventive maintenance procedures: ____________________

____

6. Pump(s)

Design life: ____________________

Elapsed operation time: ____________________

Cleanout method: ____________________

Cleanout frequency: ____________________

Cleanout duration: ____________________

Other preventive maintenance procedures: ____________________

____

7. Vacuum filter(s)/centrifuge(s) N/A

Design life: ____________________

Elapsed operation time: ____________________

Cleanout method: ____________________

Cleanout frequency: ____________________

Cleanout duration: ____________________

Other preventive maintenance procedures: ____________________

____

8. Sludge disposal pond(s)

Design life: ____________________

Elapsed operation time: ____________________

Capacity consumed: ____________________

Remaining capacity: ____________________

Cleanout procedures: ______________________________

____

J. Instrumentation See text of report (Section 3, Process Control)

A brief description of the control mechanism or method of measurement for each of the following process parameters:

- Reagent addition: ______________________________

  ____

- Liquor solids content: ______________________________

  ____

- Liquor dissolved solids content: ______________________________

  ____

- Liquor ion concentrations

  Chloride: ______________________________

  ____

  Calcium: ______________________________

  ____

  Magnesium: ______________________________

  ____

  Sodium: ______________________________

  ____

  Sulfite: ______________________________

  ____

  Sulfate: ______________________________

  ____

  Carbonate: ______________________________

  ____

  Other (specify): ______________________________

  ____

- Liquor alkalinity: ____________________

  ____

- Liquor pH: ____________________

  ____

- Liquor flow: ____________________

  ____

- Pollutant (SO_2, particulate, NO_x) concentration in flue gas: ____________________

  ____

- Gas flow: ____________________

  ____

- Waste water ____________________

  ____

- Waste solids: ____________________

  ____

Provide a diagram or drawing of the scrubber/absorber train that illustrates the function and location of the components of the scrubber/absorber control system.

Remarks: ____________________

____

____

____

____

K. Discussion of Major Problem Areas:

1. Corrosion: ____________________

   ____

   ____

2. Erosion:

3. Scaling:

4. Plugging:

5. Design problems:

6. Waste water/solids disposal:

7. Mechanical problems:

L. General comments:

APPENDIX C

PLANT SURVEY FORM

A. Company and Plant Information

1. Company name: Louisville Gas and Electric (LG&E)
2. Main office: 311 West Chestnut Street
3. Plant name: Cane Run
4. Plant location: Louisville, Kentucky
5. Responsible officer: R.L. Royer
6. Plant manager: S.J. Lindauer
7. Plant contact: Robert Van Ness
8. Position: Manager, Environmental Affairs
9. Telephone number: (502) 566-4216
10. Date information gathered: 2/22/78 and 9/11/79

Participants in meeting	Affiliation
R. Van Ness	LG&E
B. Statnick	U.S. EPA
M. Maxwell	U.S. EPA
B. Laseke	PEDCo Environmental
M. Smith	PEDCo Environmental
M. Melia	PEDCo Environmental
N. Kaplan	U.S. EPA

B. Plant and Site Data

1. UTM coordinates:

2. Sea Level elevation:

3. Plant site plot plan (Yes, No):
(include drawing or aerial overviews)

4. FGD system plan (Yes, No): Yes

5. General description of plant environs: Situated along the Ohio River in 2 moderately industrialized areas.

6. Coal shipment mode(s): Barge and truck

C. FGD Vendor/Designer Background

1. Process: Dual alkali

2. Developer/licensor: ADL/CEA*

3. Address: Acorn Park
Cambridge, MA 02140

4. Company offering process:

Company: ADL/CEA

Address: 555 Madison Ave.

---

*Arthur D. Little and Combustion Equipment Associates

Location: New York, NY 10022

Company contact: T. Frank

Position:

Telephone number: 212/980-3700

5. Architectural/engineer:

Company: Fluor-Pioneer

Address: 200 West Monore

Location: Chicago, Illinois 60606

Company contact:

Position:

Telephone number: (312) 368-3700

D. Boiler Data

1. Boiler: Cane Run 6

2. Boiler manufacturer: Combustion Engineering

3. Boiler service (base, intermediate, cycling, peak):

Base load

4. Year placed in service: 1969

5. Total hours operation (date)::

6. Remaining life of unit:

7. Boiler type: Pulverized coal

8. Served by stack no.: 6

9. Stack height: 158 m (518 ft)

10. Stack top inner diameter: 4.8 m (16 ft)

11. Unit ratings (MW):

Gross unit rating: 299

Net unit rating without FGD: 280

Net unit rating with FGD: 277

Name plate rating:

12. Unit heat rate:

Heat rate without FGD:

Heat rate with FGD: 10,508 kJ/net kWh (9,960 Btu/net kWh)

13. Boiler capacity factor, (1977): 60%

14. Fuel type: Coal

15. Flue gas flow rate:

Maximum: 503 m^3/s (1,065,000 acfm)

Temperature: 149°C (300°F)

16. Total excess air: 25% (35% max)

17. Boiler efficiency:

E. Coal Data

1. Coal supplier(s):

Name(s): Peabody Coal Company

Location(s): Star Mine

Mine location(s): Western Kentucky

County, State:

Seam:

2. Gross heating value: 27,700 J/g (11,500 Btu/lb) (maximum)

3. Ash (maximum): 14.0%

4. Moisture: 12.0% (maximum)

5. Sulfur (maximum): 4.0%

6. Chloride: 0.07% (maximum)

7. Ash composition (See Table A1)

Table A1

Constituent	Percent weight
Silica, SiO_2	Not available
Alumina, Al_2O_3	
Titania, TiO_2	
Ferric oxide, Fe_2O_3	
Calcium oxide, CaO	
Magnesium oxide, MgO	
Sodium oxide, Na_2O	
Potassium oxide, K_2O	
Phosphorous pentoxide, P_2O_5	
Sulfur trioxide, SO_3	
Other	
Undetermined	

F. Atmospheric Emission Regulations

1. Applicable particulate emission regulation
   a) Current requirement: 43 ng/J (0.1 lb/MM Btu)
      Regulation and section:
   b) Future requirement:
      Regulation and section:
2. Applicable SO_2 emission regulation
   a) Current requirement: 516 ng/J (1.2 lb/MM Btu)
      Regulation and section No.: Jefferson County KRS Chapter 77 and KRS Chapter 224
   b) Future requirement:
      Regulation and section:

G. Chemical Additives: (Includes all reagent additives - absorbents, precipitants, flocculants, coagulants, pH adjusters, fixatives, catalysts, etc.)

1. Trade name: Soda ash

Principal ingredient: Sodium carbonate

Function: SO_2 absorbent

Source/manufacturer:

Quantity employed: 1,734 Mg/yr (1,912 ton/yr)

Point of addition: Thickener

2. Trade name: Carbide lime

Principal ingredient: $Ca(OH)_2$ (92.5%)

Function: Reagent regeneration

Source/manufacturer: Airco, Inc.

Quantity employed: 53,277 Mg/yr (58,728 ton/yr)

Point of addition: Primary reactor

3. Trade name: Not applicable (N/A)

Principal ingredient:

Function:

Source/manufacturer:

Quantity employed:

Point of addition:

4. Trade name: N/A

Principal ingredient:

Function:

Source/manufacturer:

Quantity employed:

Point of addition:

5. Trade name: N/A

Principal ingredient: ______

Function: ______

Source/manufacturer: ______

Quantity employed: ______

Point of addition: ______

H. Equipment Specifications

1. Electrostatic precipitator(s)

Number: Two (2)

Manufacturer: ______

Design removal efficiency: 99.4%

Outlet temperature: 150°C (300°F)

Pressure drop: ______

2. Mechanical collector(s) N/A

Number: ______

Type: ______

Size: ______

Manufacturer: ______

Design removal efficiency: ______

Pressure drop: ______

3. Particulate scrubber(s) N/A

Number: ______

Type: ______

Manufacturer: ______

Dimensions: ______

Material, shell: ______

Material, shell lining:

Material, internals:

No. of modules per train:

No. of stages per module:

No. of nozzles or sprays:

Nozzle type:

Nozzle size:

Boiler load capacity:

Gas flow and temperature:

Liquid recirculation rate:

Modulation:

L/G ratio:

Pressure drop:

Modulation:

Superficial gas velocity:

Particulate removal efficiency (design/actual):

Inlet loading:

Outlet loading:

SO_2 removal efficiency (design/actual):

Inlet concentration:

Outlet concentration:

4. SO_2 absorber(s)

Number: Two (2)

Type: Tray tower

Manufacturer: CEA

Dimensions: 9.7 m x 13.7 m (32 ft x 45 ft)

Material, shell: A-283 carbon steel

Material, shell lining: Flake reinforced polyester

Material, internals: 317L SS, 316 SS, FRP piping

No. of modules per train: One (1)

No. of stages per module: Two (2)

Packing/tray type:

Packing/tray dimensions:

No. of nozzles or sprays:

Nozzle type:

Nozzle size:

Boiler load capacity: 60% (per module)

Gas flow and temperature: 412 m^3/s @ 52°C (436,500 acfm @ 126°F)

Liquid recirculation rate: 272 liters/s (4,318 gpm)

Modulation:

L/G ratio: 1.2 liters/m^3 (9.9 gal/1000 acf)

Pressure drop: 2.4 kPa (9.5 in. H_2O)

Modulation: 6:1 turndown

Superficial gas velocity: 2.7 m/s (9.0 ft/s)

Particulate removal efficiency (design/actual):

Inlet loading: (<43 ng/J) (<0.1 lb/10^6 Btu)

Outlet loading: (<43 ng/J) (<0.1 lb/10^6 Btu)

SO_2 removal efficiency (design/actual): 94.2%

Inlet concentration: 3471 ppm (dry)

Outlet concentration: 200 ppm (dry)

5. Wash water tray(s) N/A

Number:

Type: __________

Materials of construction: __________

Liquid recirculation rate: __________

Source of water: __________

6. Mist eliminator(s)

Number: Two (2)

Type: Chevron

Materials of construction: Polypropylene

Manufacturer: Heil

Configuration (horizontal/vertical): Horizontal

Number of stages: One (1)

Number of passes per stage: Four (4)

Mist eliminator depth: __________

Vane spacing: __________

Vane angles: __________

Type and location of wash system: N/A

Superficial gas velocity: 2.7 m/s (9.0 ft/s)

Freeboard distance: __________

Pressure drop: 0.25 kPa (1.0 in. H_2O)

Comments: __________

7. Reheater(s): Two (2)

Type (check appropriate category): __________

☐ in-line

☐ indirect hot air

☒ direct combustion

☐ bypass

☐ exit gas recirculation

☐ waste heat recovery

☐ other

Gas conditions for reheat:

Flow rate: 206 m^3/s (463,500 acfm)

Temperature: 52°C (125°F)

SO_2 concentration: 200 ppm

Heating medium: Combustion products

Combustion fuel: No. 2 fuel oil

Percent of gas bypassed for reheat: N/A

Temperature boost (ΔT): 28°C (50°F)

Energy required: 28,386,000 kJ/h (26,914,000 Btu/h)

Comments: 10.8 liters/m (171 gal/h) of No. 2 fuel oil consumed in each reheater at maximum design operating conditions.

8. Fan(s)

Number: Two (2)

Type: Forced-draft booster, centrifugal

Materials of construction: A 441 carbon steel (housing and blades)

Manufacturer:

Location: Between boiler ID fan and scrubber

Rating: 720 rpm

Pressure drop: 2.1 kPa (8.5 in H_2O)

9. Recirculation tank(s): [Primary reaction tanks]

Number: Two (2)

Materials of construction: 316L SS

Function: Regeneration/precipitation

Configuration/dimensions: 3.4 m x 4.3 m (11 ft x 14 ft)

Capacity: 37,672 liters (9952 gal)

Retention time: 4.5 min.

Covered (yes/no):

Agitator: Two (2) turbine-type 45 rpm units

10. Recirculation/slurry pump(s):

Number: Four (4) - Two (2) operating/two (2) spare

Type: Recycle

Manufacturer:

Materials of construction: Rubber-lined

Head: 40 m (130 ft)

Capacity: 290 liters/s (4600 gal)

11. Thickener(s)/clarifier(s)

Number: One (1)

Type: Flat bottom

Manufacturer:

Materials of construction: Concrete shell carbon steel interior, flake reinforced lining

Configuration: Cylindrical

Diameter: 38.1 m (125 ft)

Depth: 7 m (23 ft)

Rake speed:

Retention time:

12. Vacuum filter(s)

Number: Three (3) - Two (2) operating/One (1) spare

Type: Rotary-drum

Manufacturer:

Materials of construction: 316 SS (filter drum)

Belt cloth material: FRP

Design capacity: 2.7 kg/day (3 ton/day)

Filter area:

13. Centrifuge(s) N/A

Number:

Type:

Manufacturer:

Materials of construction:

Size/dimensions:

Capacity:

14. Interim sludge pond(s) N/A

Number:

Description:

Area:

Depth:

Liner type:

Location:

Service Life:

Typical operating schedule:

Ground water/surface water monitors:

15. Final disposal site(s)

Number: One (1)

Description: Lined pond

Area:

Depth:

Location: On-site

Transportation mode: Truck

Service life:

Typical operating schedule: Continuous hauling

16. Raw materials production N/A

Number:

Type:

Manufacturer:

Capacity:

Product characteristics:

I. Equipment Operation, Maintenance, and Overhaul Schedule

1. Scrubber(s)

Design life:

Elapsed operation time:

Cleanout method:

Cleanout frequency:

Cleanout duration:

Other preventive maintenance procedures:

2. Absorber(s)

Design life: ________________________________

Elapsed operation time: ________________________

Cleanout method: ____________________________

Cleanout frequency: __________________________

Cleanout duration: ___________________________

Other preventive maintenance procedures: ___________

____

3. Reheater(s)

Design life: ________________________________

Elapsed operation time: ________________________

Cleanout method: ____________________________

Cleanout frequency: __________________________

Cleanout duration: ___________________________

Other preventive maintenance procedures: ___________

____

4. Fan(s)

Design life: ________________________________

Elapsed operation time: ________________________

Cleanout method: ____________________________

Cleanout frequency: __________________________

Cleanout duration: ___________________________

Other preventive maintenance procedures: ___________

____

5. Mist eliminator(s)

Design life: ________________________________

Elapsed operation time: ________________________

Cleanout method: ______________________________

Cleanout frequency: ______________________________

Cleanout duration: ______________________________

Other preventive maintenance procedures: ______________

____

6. Pump(s)

Design life: ______________________________

Elapsed operation time: ______________________________

Cleanout method: ______________________________

Cleanout frequency: ______________________________

Cleanout duration: ______________________________

Other preventive maintenance procedures: ______________

____

7. Vacuum filter(s)/centrifuge(s)

Design life: ______________________________

Elapsed operation time: ______________________________

Cleanout method: ______________________________

Cleanout frequency: ______________________________

Cleanout duration: ______________________________

Other preventive maintenance procedures: ______________

____

8. Sludge disposal pond(s)

Design life: ______________________________

Elapsed operation time: ______________________________

Capacity consumed: ______________________________

Remaining capacity: ______________________________

Cleanout procedures: ______________________________

____

J. Instrumentation

A brief description of the control mechanism or method of measurement for each of the following process parameters:

- Reagent addition: ______________________________

  ____

- Liquor solids content: ______________________________

  ____

- Liquor dissolved solids content: ______________________________

  ____

- Liquor ion concentrations

  Chloride: ______________________________

  ____

  Calcium: ______________________________

  ____

  Magnesium: ______________________________

  ____

  Sodium: ______________________________

  ____

  Sulfite: ______________________________

  ____

  Sulfate: ______________________________

  ____

  Carbonate: ______________________________

  ____

  Other (specify): ______________________________

  ____

- Liquor alkalinity: ______________________________

  ____

- Liquor pH: ______________________________

  ____

- Liquor flow: ______________________________

  ____

- Pollutant (SO_2, particulate, NO_x) concentration in flue gas: ______________________________

  ____

- Gas flow: ______________________________

  ____

- Waste water ______________________________

  ____

- Waste solids: ______________________________

  ____

Provide a diagram or drawing of the scrubber/absorber train that illustrates the function and location of the components of the scrubber/absorber control system.

Remarks: ______________________________

____

____

____

____

K. Discussion of Major Problem Areas:

1. Corrosion: ______________________________

   ____

   ____

2. Erosion:

3. Scaling:

4. Plugging:

5. Design problems:

6. Waste water/solids disposal:

7. Mechanical problems:

L. General comments:

APPENDIX D
OPERATIONAL FGD SYSTEM COST DATA

Date June 27, 1978

Utility Name Louisville Gas & Electric

Address P.O. Box 32010, Louisville, KY 40232

Name of Contact - Title R. Van Ness, Mgr. Environmental Affairs

Phone No. (502)/566 - 4216

Station Cane Run

Unit Identification No. 4

Unit Size, 190 gross MW, 734,000 acfm @ 325 °F

Net MW w/o FGD 185

Net MW w/FGD 182

FGD System Size, 190 MW

734,000 acfm @ 325 °F

Foot-note No.

COST BREAKDOWN

I. CAPITAL COSTS OF FGD SYSTEM INSTALLATION

A. Year(s) to which estimates below apply: 1975

B. Year of greatest capital expenditure: 1975

C. Month and year estimates made: Mar. 1978

D. Date FGD contract awarded: April 19, 1974

Date FGD construction began: October 15, 1974

Date of initial FGD system start-up: August 3, 1976

Date of commercial FGD system start-up: Sept. 1977

E. Expected FGD system life: 13 years

F. Cost adjustment made by: L. Yerino

G. Cost adjustment checked by: M. Smith

Footnote No.		Included in reported total cost		Capital cost, $
		Yes	No	
	H. Direct capital cost			
	1. Particulate collection			
	Equipment cost	☐	☒	
	Installation cost	☐	☒	
	Total cost	☐	☒	
1	2. Facilities for reagent handling and preparation			
	Equipment cost	☒	☐	
	Installation cost	☒	☐	
	Total cost	☒	☐	496,000
2	3. SO_2 absorber and related equipment			
	Equipment cost	☒	☐	4.7 MM
	Installation cost	☒	☐	4.1 MM
	Total cost	☒	☐	8.8 MM
3	4. Fans installed for FGD			
	Equipment cost	☒	☐	
	Installation cost	☒	☐	
	Total cost	☒	☐	
4	5. Reheat			
	Equipment cost	☒	☐	
	Installation cost	☒	☐	
	Total cost	☒	☐	300,000

Foot-note No.		Included in reported total cost		Capital cost, $
		Yes	No	
5	6. Solids disposal: site			
	Equipment cost	☒	☐	
	Installation cost	☒	☐	
	Total cost	☒	☐	1.101 MM

Location of interim and final disposal site(s) on-site

When was site(s) acquired or year of expected acquisition

1945

Cost when acquired or at time of expected acquisition

Life span 10 years - can be expanded to 20 yrs. by increasing dike wall

Required site treatment (lining, surface preparation, etc.) clay

Composition of disposed material (flyash 6 %, bottom ash 24 %, SO_2 waste 33 %, unreacted reagent 3 %, water 33 %).

Foot-note No.		Included in reported total cost		Capital cost, $
		Yes	No	
	7. Solids disposal: transport system			
	Contract cost	☐	☒	
	Equipment cost	☐	☒	
	Installation cost	☐	☒	
	Total cost	☐	☒	

Foot-note No.		Included in reported total cost Yes	No	Capital cost, $
6	8. Solids disposal: treatment system			
	Equipment cost	☒	☐	
	Installation cost	☒	☐	
	Total cost	☒	☐	
	9. By-product recovery: regenerative system			
	Equipment cost	☐	☒	
	Installation cost	☐	☒	
	Total cost	☐	☒	N/A
	10. By-product recovery plant			
	Equipment cost	☐	☒	
	Installation cost	☐	☒	
	Total cost	☐	☒	N/A
7	11. Instrumentation and controls			
	Equipment cost	☒	☐	
	Installation cost	☒	☐	
	Total cost	☒	☐	
8	12. Utilities and services			
	Equipment cost	☒	☐	
	Installation cost	☒	☐	
	Total cost	☒	☐	

N/A - Not Applicable

Footnote No.			Included in reported total cost Yes	No	Capital cost, $
9	13.	Stack requirements due to FGD			
		Equipment cost	☒	☐	
		Installation cost	☒	☐	
		Total cost	☒	☐	100,000
10	14.	Additional system modifications			
		Equipment cost	☐	☒	
		Installation cost	☐	☒	
		Total cost	☐	☒	
	15.	Other			
		Equipment cost	☐	☒	
		Installation cost	☐	☒	
		Total cost	☐	☒	
	16.	Other			
		Equipment cost	☐	☒	
		Installation cost	☐	☒	
		Total cost	☐	☒	
	17.	Other			
		Equipment cost	☐	☒	
		Installation cost	☐	☒	
		Total cost	☐	☒	

Footnote No.		Included in reported total cost		Capital cost, $
		Yes	No	
	18. Other			
	Equipment cost	☐	☒	
	Installation cost	☐	☒	
	Total cost	☐	☒	
	19. Other			
	Equipment cost	☐	☒	
	Installation cost	☐	☒	
	Total cost	☐	☒	
	20. Other			
	Equipment cost	☐	☒	
	Installation cost	☐	☒	
	Total cost	☐	☒	
	Direct cost subtotal			
	Equipment cost	☒	☐	
	Installation cost	☒	☐	
	Total cost	☒	☐	10,847,000
11	I. Indirect Costs			
	1. Engineering			
12	In-house	☒	☐	
	A-E	☒	☐	
	2. Construction expenses			
	In-house	☒	☐	
	Contractor	☐	☒	

Footnote No.		Included in reported total cost Yes	No	Capital cost, $
	3. Contractor fees	☒	☐	
	4. Subcontractor fees	☒	☐	
	5. Allowance for funds used during construction	☒	☐	
	6. Allowance for start-up	☒	☐	
	7. Contingency	☒	☐	
	8. Escalation	☒	☐	
	9. Spares, offsite, taxes, freight, etc.	☐	☒	
	10. Research and development	☐	☒	
	11. Other	☐	☒	
	Indirect cost subtotal	☐	☐	1,800,000

J. Total Direct and Indirect Costs 12,647,000

$/kW (gross) 66.56

13 II. ANNUAL OPERATING COST

Footnote No.		Included in reported total cost Yes	No	Cost, $
	A. Variable Costs			
	1. Particulate removal			
	a. Operating	☐	☒	
	(1) Labor	☐	☒	
	(2) Supervision	☐	☒	
	b. Electricity	☐	☒	
	c. Other utilities	☐	☒	
	(1) Water	☐	☒	

Foot- note No.		Included in reported total cost Yes	No	Cost, $
	d. Maintenance	☐	☒	
	(1) Labor	☐	☒	____________
	(2) Supplies	☐	☒	____________
	Subtotal particulate	☐	☒	____________
	2. SO_2 absorber			
	a. Operating	☐	☐	
	(1) Labor	☒	☐	____________
	(2) Supervision	☒	☐	____________
	b. Electricity consumption			
	(1) Feed preparation	☒	☐	____________
	(2) Reheat	☒	☐	____________
	(3) Fans	☒	☐	____________
	(4) SO_2 absorber	☒	☐	____________
	(5) Other	☒	☐	____________
	c. Fuel			
	(1) Reheat	☒	☐	____________
	(2) Other	☐	☐	____________
	d. Other Utilities			
	(1) Water	☒	☐	____________
	(2) Other	☐	☒	____________
	e. Maintenance			
	(1) Labor	☒	☐	____________
	(2) Supplies	☒	☐	____________

Foot-note No.		Included in reported total cost		Cost, $
		Yes	No	
	Subtotal absorber	☒	☐	
	3. Raw materials			
	a. Lime	☒	☐	
	b. Limestone	☐	☒	
	c. Fuel for process needs	☐	☒	
	d. Sodium hydroxide	☐	☒	
	e. Magnesium oxide	☐	☒	
	f. Sodium carbonate	☐	☒	
	g. Flocculant	☒	☐	
	h. Other	☐	☒	
	Subtotal raw materials	☒	☐	
	4. Solid and liquid waste disposal			
	a. Operating			
	(1) Labor	☒	☐	
	(2) Supervision	☒	☐	
	b. Electricity consumption	☒	☐	
	c. Other utilities			
	(1) Water	☒	☐	
	(2) Other	☐	☐	
	d. Maintenance			
	(1) Labor	☒	☐	
	(2) Supplies	☒	☐	
	e. Other	☐	☒	
	f. Credit for by-product recovery	☐	☒	

Footnote No.		Included in reported total cost		
		Yes	No	Cost, $
	g. Wastewater treatment	☐	☒	
	Subtotal disposal	☒	☐	
	5. Overhead			
	a. Plant	☐	☒	
	b. Administrative	☐	☒	
	Subtotal indirect	☐	☒	
	Total Variable Costs	☒	☐	
	B. Fixed Charges			
	1. Interest	☒	☐	
	2. Annual depreciation	☒	☐	
	3. Insurance	☐	☒	
	4. Taxes	☐	☒	
	5. Other, specify	☐	☒	
	Total Fixed Costs	☐	☐	
14	C. Total Variable and Fixed Costs			
	mills/kWh(net)	2.75		

FOOTNOTES

Line	Page	Comments
1	2	Reagent handling and preparation costs include barge handling (carbide lime) and unloading facilities, pumping system, day tank, lines and pumps and live storage tank.
2	2	Modifications to the absorber by AAF are not included as the costs were underwritten by the vendor.
3	2	Fan equipment includes two booster fans. These costs are included in item 3. Total fan ΔP=12.8 in. H_2O at full load.
4	2	Reheat costs include two burners using No. 2 fuel oil creating a temperature rise of 50°F. Also included are two air injection fans. Total cost given in 1978 dollars.
5	3	Total sludge disposal site cost is $4 MM (units 4,5,6). At a 10 yr. expected life the cost for unit 4 would be $4 MM x 190/690 = $1.101 MM. To expand life span to twenty years $900,000 must be added for additional dike construction yielding a total of $2 MM.
6	4	Solids disposal system treatment costs are included in item 6.
7	4	Instrumentation and control costs are included in item 3.
8	4	Utilities and service costs are included in item 3.
9	5	The stack is lined with pre-crete attached to a wire mesh.
10	5	Modification costs were absorbed by AAF. Major system modifications included mist eliminator replacement, increasing absorber L/G, installation of a reheat system, duct and stack liner replacement and installation of turning vanes.
11	6	Indirect cost breakdown was not available.
12	6	LG&E saved an estimated 20% on construction expenses by using their own construction forces.

FOOTNOTES

Line	Page	Comments
13	7	No annual operating cost breakdown was available. The only reported annual cost was 2.5-3.0 mills/kWh (estimated.)
14	10	2.75 mills/kWh representing an average of the range reported.

APPENDIX D

COST ADJUSTMENTS

1. Total Reported Capital Cost Direct and Indirect $12,647,000
66.56 $/kW

2. Correct Expenditures to July 1, 1977;

	Conversion Factor to July 1, 1977	% of Total	AAF Expenditures	L,G&E Expenditure	Corrected to July 1, 1977
1973	1.417	0.3		34,000	48,000
1974	1.234	4.0		416,000	513,000
1975	1.12	30.0	50,000	2,924,000	3,331,000
1976	1.062	80.0	450,000	5,623,000	6,450,000
1977	1.00	100.0	500,000	2,249,000	2,749,000
1978	.949			1,401,000	330,000
					14,421,000

- Cost to increase waste disposal site life to 20 years = + 900,000
- Total Adjusted Capital Expenditure $15,321,000

80.64 $/kW

3. Reported Annual Cost 2.75 mills/kWh

4. Adjusted Annual Cost (Pedco Estimates @ 65% cf);

Variable Costs

A) SO_2 Absorber

- Operating - manpower and respective costs shown are for units 4.5 & 6 with the operating subtotal being proportioned by MW for unit four only. Pedco estimated manpower cost @ $8.50/hr used.

APPENDIX D

COST ADJUSTMENTS

(1) Labor (@ 10 men per shift)	745,000
(2) Supervision (@ 1 man per shift)	74,000
(3) Labor: barge facilities, etc. (@ 5 men per shift)	372,000
Subtotal Operating (units 4,5 & 6)	$1,191,000
o Total absorber operating labor cost (unit four only) 1,191,000 x 190/690 =	$ 328,000
o Electricity Consumption (Estimation @ 12 mills/kWh)	234,000
o Fuel for reheat (Estimation @ $13/barrel & 30 GPM)	3,172,000
o Maintenance	
(1) Labor (estimated @ 4% of capital cost)	613,000
(2) Supplies (estimated @ 15% of labor)	92,000
B) Raw Materials	
o Lime (estimated @ $8/ton)	1,147,000
o Lime handling cost	717,000
o Flocculant (estimated @ $1.80/lb.)	13,000
C) Overhead	
o Plant (estimated @ 50% O+M)	360,000
o Administrative (estimated @ 20% of operating labor)	43,000
Total Variable Costs	$6,719,000

APPENDIX D

COST ADJUSTMENTS

Fixed Charges, %

° Cost of Money	6.25
° Annual Depreciation	3.33
° Insurance	0.30
° Taxes	4.00
° Interim Replacement	0.70
	14.58%

Total Fixed Cost = .1458 x 15,321,000 = $2,234,000

Variable	6,719,000
Fixed	2,234,000
Total Adjusted Annual Cost	8,953,000

Net kWh Generated

182 MW x 1000 kW/MW x 8760 hr/yr. x .65 cf = 1,036,308.000 kWh

6,719,000/1,036,308,000 = 6.484 mills/kWh Variable

2,234,000/1,036,308,000 = 2.156 mills/kWh Fixed

8.640 mills/kWh Total

APPENDIX E
OPERATIONAL FGD SYSTEM COST DATA

Date June 28, 1978

Utility Name Louisville Gas & Electric

Address P.O. Box 32010, Louisville, KY 40232

Name of Contact - Title R. Van Ness, Manager of Environmental Affairs

Phone No. (502)/566-4216

Station Cane Run

Unit Identification No. 5

Unit Size, 200 gross MW, 700,000 acfm @ 310 °F

Net MW w/o FGD 195

Net MW w/FGD 191.5

FGD System Size, 200 MW

700,000 acfm @ 310 °F

Foot-note No.

COST BREAKDOWN

I. CAPITAL COSTS OF FGD SYSTEM INSTALLATION

A. Year(s) to which estimates below apply: 1975-1977

B. Year of greatest capital expenditure: 1977

C. Month and year estimates made: March 1978

D. Date FGD contract awarded: April 21, 1975

Date FGD construction began: October 1, 1975

Date of initial FGD system start-up: December 1977

Date of commercial FGD system start-up: June 1, 1978

E. Expected FGD system life: 12 years

F. Cost adjustment made by: L. Yerino

G. Cost adjustment checked by: B. A. Laseke, Jr.

Foot-note No.		Included in reported total cost		Capital cost, $
		Yes	No	
	H. Direct capital cost			
	1. Particulate collection			
	Equipment cost	☐	☒	
	Installation cost	☐	☒	
	Total cost	☐	☒	
1	2. Facilities for reagent handling and preparation			
	Equipment cost	☒	☐	
	Installation cost	☒	☐	
	Total cost	☒	☐	1,800,000
2	3. SO_2 absorber and related equipment			
	Equipment cost	☒	☐	5,768,000
	Installation cost	☒	☐	5,032,000
	Total cost	☒	☐	10,800,000
3	4. Fans installed for FGD			
	Equipment cost	☒	☐	
	Installation cost	☒	☐	
	Total cost	☒	☐	
4	5. Reheat			
	Equipment cost	☒	☐	
	Installation cost	☒	☐	
	Total cost	☒	☐	650,000

Foot-note No.		Included in reported total cost Yes	No	Capital cost, $
5	6. Solids disposal: site			
	Equipment cost	☒	☐	
	Installation cost	☒	☐	
	Total cost	☒	☐	1,159,000

Location of interim and final disposal site(s) On-site

When was site(s) acquired or year of expected acquisition 1945

Cost when acquired or at time of expected acquisition

Life span 10 yrs. - can be expanded to 20 years by increasin dike wall

Required site treatment (lining, surface preparation, etc.) clay

Composition of disposed material (flyash 6 %, bottom ash 24 %, SO_2 waste 33 %, unreacted reagent 3 %, water 33 %).

Foot-note No.		Yes	No	Capital cost, $
6	7. Solids disposal: transport system			
	Contract cost	☐	☒	
	Equipment cost	☒	☐	
	Installation cost	☒	☐	
	Total cost	☒	☐	

Footnote No.			Included in reported total cost Yes	No	Capital cost, $
7	8.	Solids disposal: treatment system			
		Equipment cost	☒	☐	
		Installation cost	☒	☐	
		Total cost	☒	☐	
	9.	By-product recovery: regenerative system			
		Equipment cost	☐	☒	
		Installation cost	☐	☒	
		Total cost	☐	☒	N/A
	10.	By-product recovery plant			
		Equipment cost	☐	☒	
		Installation cost	☐	☒	
		Total cost	☐	☒	N/A
8	11.	Instrumentation and controls			
		Equipment cost	☒	☐	
		Installation cost	☒	☐	
		Total cost	☒	☐	
9	12.	Utilities and services			
		Equipment cost	☒	☐	
		Installation cost	☒	☐	
		Total cost	☒	☐	

N/A - not applicable

Footnote No.			Included in reported total cost Yes	No	Capital cost, $
10	13.	Stack requirements due to FGD			
		Equipment cost	☐	☒	
		Installation cost	☐	☒	
		Total cost	☐	☒	
	14.	Additional system modifications			
		Equipment cost	☐	☒	
		Installation cost	☐	☒	
		Total cost	☐	☒	
11	15.	Other			
		Equipment cost	☒	☐	
		Installation cost	☒	☐	
		Total cost	☒	☐	
	16.	Other			
		Equipment cost	☐	☒	
		Installation cost	☐	☒	
		Total cost	☐	☒	
	17.	Other			
		Equipment cost	☐	☒	
		Installation cost	☐	☒	
		Total cost	☐	☒	

Foot-note No.		Included in reported total cost		Capital cost, $
		Yes	No	
	18. Other			
	Equipment cost	☐	☒	
	Installation cost	☐	☒	
	Total cost	☐	☒	
	19. Other			
	Equipment cost	☐	☒	
	Installation cost	☐	☒	
	Total cost	☐	☒	
	20. Other			
	Equipment cost	☐	☒	
	Installation cost	☐	☒	
	Total cost	☐	☒	
	Direct cost subtotal			
	Equipment cost	☒	☐	
	Installation cost	☒	☐	
	Total cost	☒	☐	Included in total capital
	I. Indirect Costs			
12	1. Engineering			
	In-house	☒	☐	
	A-E	☒	☐	
	2. Construction expenses			
	In-house	☒	☐	
	Contractor	☒	☐	

Foot-note No.		Included in reported total cost Yes	Included in reported total cost No	Capital cost, $
	3. Contractor fees	☒	☐	
	4. Subcontractor fees	☒	☐	
	5. Allowance for funds used during construction	☒	☐	
	6. Allowance for start-up	☒	☐	
	7. Contingency	☒	☐	
	8. Escalation	☒	☐	
	9. Spares, offsite, taxes, freight, etc.	☒	☐	
	10. Research and development	☐	☒	
	11. Other	☒	☐	
	Indirect cost subtotal	☐	☐	Included in total capital

J. Total Direct and Indirect Costs $12,481,000

$/kW (gross) $62.4

II. ANNUAL OPERATING COST

Foot-note No.		Included in reported total cost Yes	Included in reported total cost No	Cost, $
13	A. Variable Costs			
	1. Particulate removal			
	a. Operating	☐	☐	
	(1) Labor	☐	☐	
	(2) Supervision	☐	☐	
	b. Electricity	☐	☐	
	c. Other utilities	☐	☐	
	(1) Water	☐	☐	

Foot-note No.		Included in reported total cost		Cost, $
		Yes	No	
	d. Maintenance	☐	☐	
	(1) Labor	☐	☐	____________
	(2) Supplies	☐	☐	____________
	Subtotal particulate	☐	☐	____________
	2. SO_2 absorber			
	a. Operating	☐	☐	
	(1) Labor	☐	☐	____________
	(2) Supervision	☐	☐	____________
	b. Electricity consumption			
	(1) Feed preparation	☐	☐	____________
	(2) Reheat	☐	☐	____________
	(3) Fans	☐	☐	____________
	(4) SO_2 absorber	☐	☐	____________
	(5) Other	☐	☐	____________
	c. Fuel			
	(1) Reheat	☐	☐	____________
	(2) Other	☐	☐	____________
	d. Other Utilities			
	(1) Water	☐	☐	____________
	(2) Other	☐	☐	____________
	e. Maintenance			
	(1) Labor	☐	☐	____________
	(2) Supplies	☐	☐	____________

Foot-note No.		Included in reported total cost		Cost, $
		Yes	No	
	Subtotal absorber	☐	☐	______
	3. Raw materials			
	a. Lime	☐	☐	______
	b. Limestone	☐	☐	______
	c. Fuel for process needs	☐	☐	______
	d. Sodium hydroxide	☐	☐	______
	e. Magnesium oxide	☐	☐	______
	f. Sodium carbonate	☐	☐	______
	g. Flocculant	☐	☐	______
	h. Other	☐	☐	______
	Subtotal raw materials	☐	☐	______
	4. Solid and liquid waste disposal			
	a. Operating			
	(1) Labor	☐	☐	______
	(2) Supervision	☐	☐	______
	b. Electricity consumption	☐	☐	______
	c. Other utilities			
	(1) Water	☐	☐	______
	(2) Other	☐	☐	______
	d. Maintenance			
	(1) Labor	☐	☐	______
	(2) Supplies	☐	☐	______
	e. Other	☐	☐	______
	f. Credit for by-product recovery	☐	☐	______

Footnote No.		Included in reported total cost		Cost, $
		Yes	No	
	g. Wastewater treatment	☐	☐	
	Subtotal disposal	☐	☐	
	5. Overhead			
	a. Plant	☐	☐	
	b. Administrative	☐	☐	
	Subtotal indirect	☐	☐	
	Total Variable Costs	☐	☐	
	B. Fixed Charges			
	1. Interest	☐	☐	7.25%
	2. Annual depreciation	☐	☐	8.33%
	3. Insurance	☐	☐	
	4. Taxes	☐	☐	4.00%
	5. Other, specify (Int. Repl.)	☐	☐	0.30%
	Total Fixed Costs	☐	☐	19.88%
	C. Total Variable and Fixed Costs	See Adjustment		
	mills/kWh(net)			

FOOTNOTES

Line	Page	Comments
1	2	Reagent handling and preparation facility includes barge handling (carbide lime) and unloading facility, three separate pumping systems for units 4,5 and 6, day tank, lines and pumps and live storage tank (1MM gal.).
2	2	Design SO_2 removal efficiency is 85%.
3	2	Approximate total FGD ΔP is 13 in H_2O. Ductwork = 5 in, steam coils = 1-2 in, flooded elbow = 3 in, tray = 1.5 in. Fan costs are included in item 3.
4	2	Reheat type is finned coils - steam. Estimated cost is $650,000 and is included in item no. 3. ΔT = 40°F.
5	3	Total cost for solid disposal site is $4 MM for units 4, 5, and 6. Cost breakdown for unit 5 is ($4 MM)x(200/690) = $1,159,000
6	3	Solids disposal transport system costs are included in items 3 and 6.
7	4	Discharge from the thickener underflow will go to the vacuum filter and then be mixed with flyash and lime for all three units. IUCS system treatment estimate is included in item 6.
8	4	Instrumentation costs are included in item 3 and other related areas. This includes SO_2 analyzer, Dupont 460A, measuring at two inlet and two outlet points.
9	4	Utilities and service costs are included in item 3.
10	5	No stack modifications are required - reheat will be operated when FGD system is in service.
11	5	This category includes change from original double marble bed tower to spray tower with ability to insert both marble beds and one common reaction tank. This cost is included in item 3.
12	6	Indirect costs are included in total capital cost figure.

FOOTNOTES

Line	Page	Comments
13	7	No annual costs were reported because of the system's recent operating status (initial service in Dec. 1977; earnest operation of the system actually commenced in Apr. 1978).

APPENDIX E

COST ADJUSTMENTS

Total Annual Costs;	3,790,000	VARIABLE
	2,276,000	FIXED
	\$6,066,000	TOTAL

Net kWh Generated;

191,500 kW x 8760 hr x .65 C.F. = 1,090,401,000 kWh

$$\frac{6,066,000}{1,090,401,000} = 5.562 \text{ mills/kWh TOTAL}$$

$$\frac{3,790,000}{1,090,401,000} = 3.475 \text{ mills/kWh VARIABLE}$$

$$\frac{2,276,000}{1,090,401,000} = 2.087 \text{ mills/kWh FIXED}$$

3. Summary of Adjusted Costs

°	Capital	\$13,506,000	67.53 \$/kW
°	Annual	\$ 6,087,000	5.562 mills/kWh

APPENDIX E

COST ADJUSTMENTS

1. Capital Costs

- Total reported direct and indirect cost $12,481,000
  62.41 $/kW

- Correct expenditures to July 1, 1977

	% of Total	Expenditure	Corr. factor	1977 $
1974	0.3	37,000	1.234	46,000
1975	6.3	749,000	1.12	839,000
1976	32.3	3,245,000	1.063	3,449,000
1977	72.0	4,955,000	1.0	4,955,000
1978	100.0	3,495,000	.949	3,317,000
				$12,606,000
Cost to increase solids disposal site life to 20 yrs.				+900,000
				$13,506,000
				67.53 $/kW

2. Annual Costs

The following are PEDCo estimates based on a 65% load factor:

A) SO_2 absorber operating labor (supervision, labor at barge facility, etc.) @ 8.50/hr. - $224,000

B) Electricity consumption @ 12 mills/kWh - $239,000

C) Reheat fuel @ $24/ton and 3344 lb/hr coal - $229,000

D) Maintenance
Labor @ 4% of total capital expenditure - $545,000
Supplies @ 15% of labor charge - $82,000

E) Raw materials and handling carbide lime $1,954,000 and flocculant $14,000

F) Overhead

Plant:	$428,000
Administrative:	$ 75,000
	$3,790,000

G) Fixed costs:

Cost of money	7.25%
Depreciation	5.00%
Insurance	0.30%
Taxes	4.00%
Int. Replacement	0.30%
	16.85%

(.1685) ($13,506,000) ≅ $2,276,000

APPENDIX F

PLANT PHOTOGRAPHS

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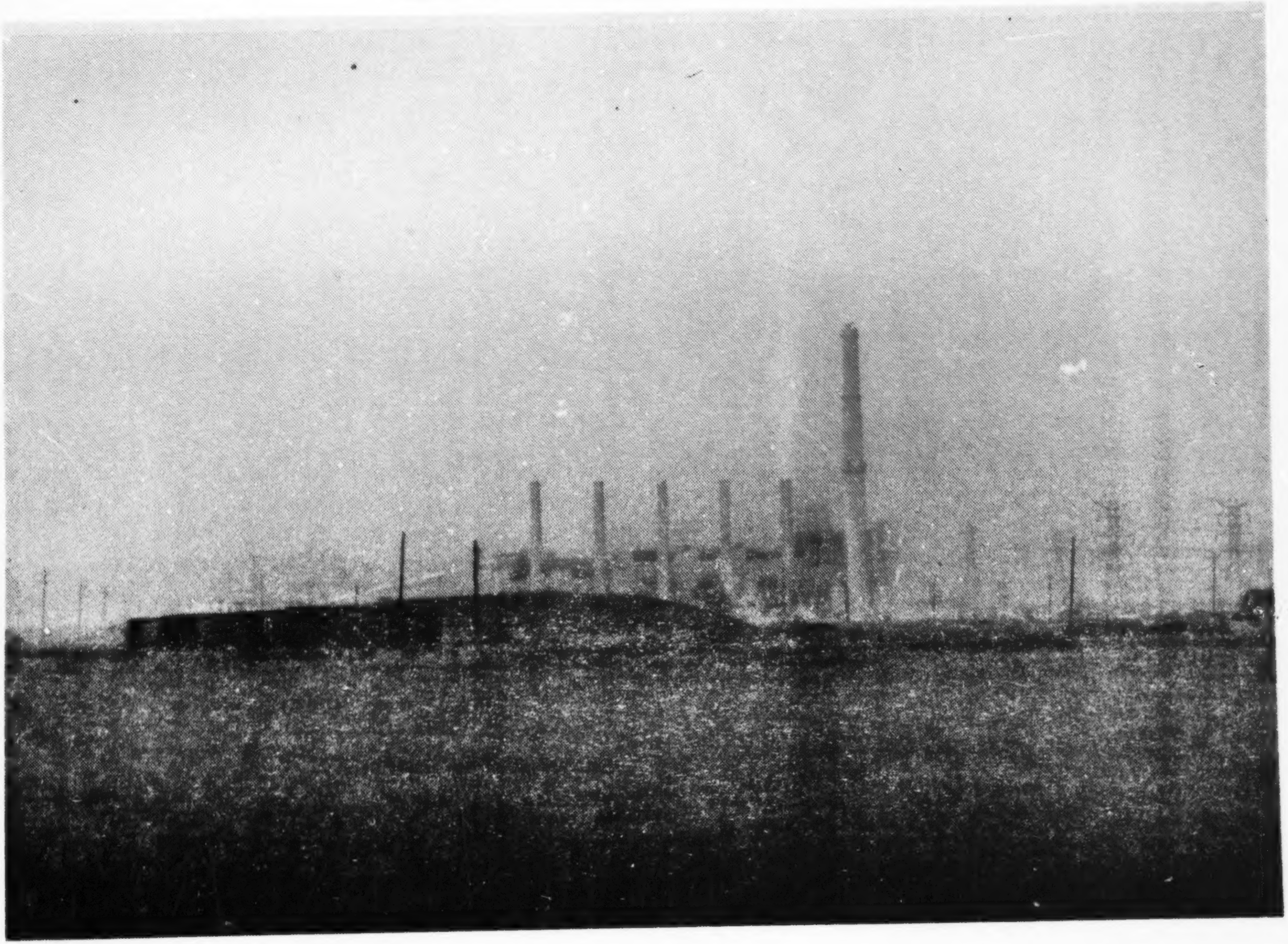

Photo No. 1. Full view of Cane Run Power Station. Units 1 to 6 are featured from left to right.

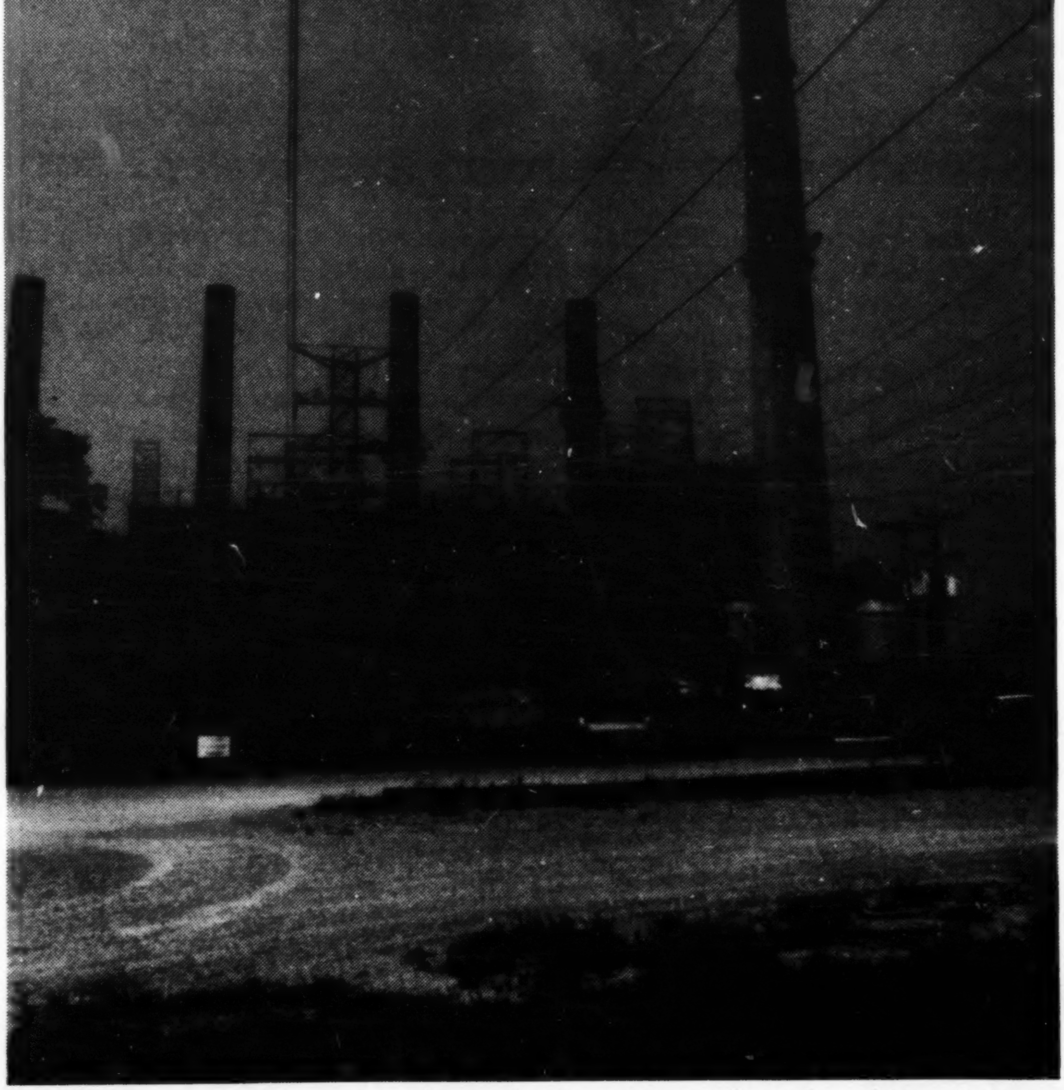

Photo No. 2. Close-up view of the FGD-equipped units at Cane Run. Cane Run 4, 5, and 6 are featured from left to right. Each FGD system contains two parallel scrubber modules.